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ANALYSES OF THE WATERS
OF
THE HOT SPRINGS OF ARKANSAS

By J. K. HAYWOOD

AND

GEOLOGICAL SKETCH OF HOT SPRINGS, ARKANSAS

BY

WALTER HARVEY WEED



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ANALYSES OF THE WATERS AND GEOLOGICAL SKETCH OF THE HOT SPRINGS OF ARKANSAS.

INTRODUCTION.

The matter contained in this publication was originally issued as Senate Document 282, Fifty-seventh Congress, first session. It is reprinted here without material change in content, the analyses being printed in slightly different form in order to save space. The introductory matter has been added.

HISTORICAL NOTES.

The Arkansas Hot Springs have been known since the early settlement of Louisiana. Although it is only a legend that they were visited by De Soto on his trip to the Mississippi, there is no doubt that they were used by the Indians before the advent of Columbus, as abundant evidence was found in early days that the Indians quarried the dense rocks near the Hot Springs for arrowheads and spearheads and utilized the spring waters for bathing.

In 1804 two members of the Lewis and Clarke exploring expedition visited the place and found that white visitors had already used the waters for bathing. In 1818 the lands on which the springs are located were ceded to the General Government by the Quapaw Indians and became afterwards a part of the Territory of Arkansas. The ground about the springs was located by various claimants before the organization of the Territory of Arkansas, but by act of Congress the springs and the ground about them were reserved in 1834 for the United States Government, thus making the first national park reservation of the country. Owing to the claims made by various parties to a private ownership of the springs they remained in the possession of such claimants until the United States Supreme Court decided in favor of the Government in 1877.

The act of Congress of March 3, 1877, provided for the appointment by the President of three commissioners, whose duties are defined by said act as follows:

SEC. 3. That it shall be the duty of said commissioners, after examination of the topography of the reservation, to lay out into convenient squares, blocks, lots, avenues, streets, and alleys, the lines of which shall correspond with the existing boundary lines of occupants of said reservation as near as may be consistent with the interests of the United States, the following described lands, to wit: The south half of section twenty-eight, the south half of section twenty-nine, all of sections thirty-two and thirty-three, in township two south and range nineteen west; and the north half of section four, the north half of section five, in township three south and range nineteen west, situate in the county of Garland and State of Arkansas, and known as the Hot Springs Reservation.

SEC. 4. That before making any subdivision of said lands, as described in the preceding section, it shall be the duty of said board of commissioners, under the direction and subject to the approval of the Secretary of the Interior, to designate a tract of land included in one boundary, sufficient in extent to include, and which shall include, all the hot or warm springs situate on the lands aforesaid, to embrace, as near as may be, what is known as Hot Springs Mountain, and the same is hereby reserved from sale, and shall remain under the charge of a superintendent, to be appointed by the Secretary of the Interior: *Provided, however,* That nothing in this section shall prevent the Secretary of the Interior from fixing a special tax on water taken from said springs, sufficient to pay for the protection and necessary improvement of the same.

In the year mentioned a commission was appointed and recommended a permanent plan of improvement. Under that plan the land not needed for permanent reservation was platted in streets and alleys, and lots were assigned to various individuals. The original reservation consisted of 2,529 acres, of which 700 acres were awarded to individuals for business and residence purposes, 358 acres were used for streets and alleys, and 570 acres were platted in town lots reserved for future disposal.

In 1876 the town of Hot Springs was incorporated, and in 1881 the General Government donated to the city the ground platted for streets and alleys. The congressional enactment of June 16, 1880, provided as follows:

SEC. 3. That those divisions of the Hot Springs Reservation, known as the mountainous districts, not divided by streets on the maps made by the commissioners, but known and defined on the map and in the report of the commissioners as North Mountain, West Mountain, and Sugar Loaf Mountain, be, and the same are hereby, forever reserved from sale, and dedicated to public use as parks, to be known, with Hot Springs Mountain, as the permanent reservation.

THE RESERVATION.

Under the two acts mentioned above the mountains adjacent to the springs are permanently reserved. The Hot Springs Reservation contains 911.63 acres, and includes Hot Springs Mountain, North Mountain, West Mountain, Sugar Loaf Mountain, and Whittington Lake Park. The springs are all grouped about the base of Hot Springs Mountain, their aggregate flow being 826,308 gallons per day. The hot water is supplied to the various bathhouses, and the receipts from this source are all expended under the direction of the Secretary of the Interior in improving the service and in developing and beautifying the reservation. There are more than 11 miles of well-built roads and footpaths over the mountains.

The Government is represented at the springs by a superintendent and a medical director, both appointed by the Secretary of the Interior. The superintendent has supervision over all general matters connected with the Government's interests, is disbursing officer, and enforces the rules and regulations of the department. The medical director has charge of sanitation, hydrotherapy, the bathing of patients, the Government free bathhouse for the indigent, the instruction and supervision of bath attendants, and the determination as to their fitness for employment.

THE PAY BATHHOUSES.

There are 23 pay bathhouses operated under rules and regulations approved by the Secretary of the Interior. Eleven are on the reser-

vation at the base of Hot Springs Mountain, constituting what is known as "Bathhouse Row," and 12 are located at various points in the city. Eleven are in connection with hotels, hospitals, or sanatoria. The water is the same in all, but the prices charged for the baths vary in the different houses in accordance with the equipments and accommodations furnished. The rates are fixed in each instance by the Secretary of the Interior. The charges for the services of the attendants are the same in all, and include all the necessities of the bath except furnishing and laundering towels, bath robes, and mitts, rubbing mercury, and handling helpless invalids.

THE ARMY AND NAVY GENERAL HOSPITAL.

The Army and Navy General Hospital is also supplied with water from the springs. It is administered by the War Department for the benefit of officers and enlisted men of the military and naval service of the United States, cadets at the United States Military and Naval Academies, officers of the Revenue-Cutter Service, officers of the Public Health and Marine-Hospital Service, and honorably discharged soldiers and sailors of the Regular and Volunteer Army and Navy of the United States who are suffering from such diseases as the waters of the hot springs of Arkansas have an established reputation in benefiting.

Admission to this hospital of all such cases regardless of their severity is not, however, contemplated. Its facilities will not be extended to mild and transient cases which should yield to ordinary treatment, but are reserved for those of a serious and obstinate character, which, though resisting ordinary methods of relief, promise a rapid and permanent recovery from the use of the waters of the springs.

Application for admission to this institution should be made to the Adjutant General, United States Army, at Washington, D. C.

THE GOVERNMENT FREE BATHS.

The Government free bathhouse for the indigent was established pursuant to act of Congress of December 16, 1878. The number of baths given to the poor during the year 1910 was 200,048.

The act of March 2, 1911, provides that an applicant for free baths shall be required to make oath that he is without and unable to obtain means to pay for baths, and a false oath as to his financial condition makes him guilty of a misdemeanor and subjects him, upon conviction thereof, to a fine of not to exceed \$25, or 30 days' imprisonment, or both.

Tickets are issued only to those who, after examination, are found to be suffering from diseases that may reasonably be expected to be benefited by the baths. Children are not allowed in the bathhouse unless they themselves are patients.

Those who intend making application for these baths are advised that no other treatment is provided. There is no hospital attached, and they must provide their own board and lodging. There are no hospitals in the city of Hot Springs to which patients can be admitted free of charge, nor are any funds available from which relief can be afforded or railroad transportation furnished to their homes.

This statement appears necessary, as many destitute invalids come each year from other and distant States in the belief that the Government maintains a public institution at which they will be cared for free of charge.

THE CHARACTER AND ACTION OF THE WATERS.

The source of the heat is believed to be great masses of igneous rock intruded in the earth's crust by volcanic agencies. Deep-seated waters converted into vapors by contact with this heated mass probably ascend through fissures toward the surface where they meet cold springs, which are heated by the vapors.

The waters are radioactive in a marked degree, and to the presence of this rare element in gaseous form is now generally attributed their salutary effects. The baths create a reaction accompanied by an elevation of body temperature, accelerated heart action with diminished blood pressure in the arteries, and a stimulation of the nutritive changes in the tissue cells, especially those composing the organs of elimination and those concerned in the formation of the blood. The mineral constituent is very low, and when the waters are taken internally, combined with the sweating produced by the baths and packs, elimination by all the emunctories is greatly increased.

The hot waters may reasonably be expected to give relief in the following conditions: In gout or rheumatism after the acute or inflammatory stage; in neuralgia when dependent upon gout, rheumatism, malaria, or metallic poisoning; in the early stages of chronic Bright's disease; in catarrhal conditions of the gall bladder; in certain forms of disease of the pelvic organs, and in sterility in women; in chronic malaria, alcoholism, and drug addictions; in many chronic skin diseases; in some forms of anemia; in syphilis; in gonorrheal rheumatism; in toxemias and conditions of defective elimination; and in some forms of cardiovascular disease with increased tension in the blood vessels.

The general tonic and recuperative effects are marked in conditions of debility and neurasthenia due to the strain and fatigue incident to social and business cares and responsibilities, and in many other conditions the baths and climate are useful aids to medical treatment. The reservation parks afford opportunities for out-of-door life, driving, riding, automobiling, and hill climbing. Much importance is attached by local physicians to the possibilities for out-of-door life.

The baths are contraindicated in tuberculosis of the throat and lungs and in all forms of cancer.

PHYSICIANS.

The only physicians who are allowed to prescribe the waters of the hot springs are those licensed practitioners of the State of Arkansas who have been examined by a Federal board of medical examiners appointed by the Secretary of the Interior. Visitors are warned that physicians who have not passed the Federal board and been registered in the superintendent's office, are not permitted to make use of the baths in the treatment of their patients. This rule is for

the protection of visitors who, if they desire the baths, should before employing a physician, procure from the superintendent of the reservation a list of the qualified practitioners.

While the baths may be taken without the advice of a physician by procuring a permit at the office of the superintendent, this practice is not recommended. Patients who assume to determine the nature of their ailments, and to prescribe for themselves, often fail to obtain the desired relief. The waters are not beneficial in all diseases and in some are harmful. It is a useless expenditure of time and money to take the baths for a disease that will not be benefited by them, and such procedure can only result in delaying proper treatment.

Physicians' fees are from \$25 a month up, according to the treatment required.

Visitors are advised for their own protection that soliciting for hotels, boarding houses, or doctors on the trains running into Hot Springs is in violation of law, and are warned against heeding the advice of irresponsible and unknown persons.

In the interest of the public it has been found necessary to prohibit the bathing of anyone stopping at a hotel or boarding house in which the solicitation of patronage for doctors is allowed. Such solicitation usually takes the form of advising the patient that the doctor to whom he has been recommended by a friend at home is out of town, but that Dr. X is as good a man and will treat him for less money. The drummer commonly poses as a greatly benefited and grateful patient of the doctor who employs him. Doctors who make use of agents to induce patients to take treatment from them usually divide their fees with the solicitors or drummers.

The moral responsibility of good citizenship demands that visitors should make known to the superintendent of the reservation any instance of soliciting for doctors, thus effectively aiding the department in eliminating an obnoxious practice, and insuring to themselves the full benefits of proper treatment at this resort.

RAILROADS.

The railroads running into Hot Springs are the Chicago, Rock Island & Pacific and the St. Louis, Iron Mountain & Southern. Through cars are operated from many of the larger cities. Detailed information can be obtained from local ticket agents.

THE CITY OF HOT SPRINGS.

The city of Hot Springs has extended beyond the narrow valley in which the springs are located and spread out over the open plain to the south and east. It is supplied with all the public utility services of the larger cities. There are churches of every denomination, public and private schools, hospitals and sanatoria, theaters and other places of amusement, a race track, and the State fair grounds. The resident population is about 16,000.

There are many hotels, the largest affording accommodations for 1,000 guests, and several hundred boarding houses ranging in price from \$5 a week up. Cottages and apartments for light housekeeping, furnished or unfurnished, can be rented from \$10 a month up. The cost of living is about the same as in average cities of like size.

Lists of hotels and boarding houses can be obtained at the Business Men's League, which is located next to the post office, and inquiries of a general nature not related to the administration of the baths will be answered by its secretary.

The climate is good throughout the year. In the earlier days Hot Springs was exclusively a summer resort, the hotels being closed from October to March. In later years, however, owing to the number who come during the winter months to escape the cold of the north, the resort is patronized throughout the year. There is no malaria.

The elevation of the city is 600 feet, and that of the surrounding hills about 1,200 feet above the level of the sea.

THE CHEMICAL COMPOSITION OF THE WATERS OF THE HOT SPRINGS OF ARKANSAS.¹

By J. K. Haywood.

Chief of Miscellaneous Division, Bureau of Chemistry.

INTRODUCTION.

The Hot Springs of Arkansas are situated in Garland County immediately adjacent to Hot Springs City, on the western slope and at the base of Hot Springs Mountain, a spur of the Ozark Range. Originally there were said to have been 71 of these springs, but on account of improvements on the mountain, necessitating the merging of two or more springs into one, also by reason of the natural changes in the subterranean course of the water, this number has been reduced to 49. Forty-four of these are either in use or can easily be used by making some slight improvements. Five rise from the bed of the creek situated at the base of the mountain, and are consequently lost in the cold water of the stream. Besides the hot springs mentioned above, there are two cold springs in close juxtaposition on the northern slope of the mountain.

In making the analyses of these waters, because of changes apt to take place in certain constituents on standing, some of the determinations were made directly on the ground within one hour after the samples had been taken. The determinations mentioned are nitrogen, oxygen, carbon dioxide (free and as bicarbonates), nitrites, nitrates, oxygen consuming capacity, and free and albuminoid ammonia. Besides this, 10-gallon samples of each spring were shipped to Washington, D. C., where determinations of the various mineral constituents were at once begun. Each day the temperature of the spring then under analysis was taken; finally at the end of the chemist's stay at Hot Springs the temperatures were retaken in a single day, as well as the flow of each spring.

The constituents determined in each of the 44 hot springs and in the 2 cold springs include the following:

| | |
|-----------------------------|--------------------|
| Oxygen, consuming capacity. | Chlorine. |
| Albuminoid ammonia. | Boric acid. |
| Free ammonia. | Phosphoric acid. |
| Lithium. | Nitric acid. |
| Sodium. | Nitrous acid. |
| Potassium. | Sulphuric acid. |
| Magnesium. | Silicic acid. |
| Calcium. | Carbonic acid. |
| Iron and aluminum. | Bicarbonic acid. |
| Manganese. | Nitrogen. |
| Arsenic. | Oxygen. |
| Iodine. | Hydrogen sulphide. |
| Bromine. | Total solids. |

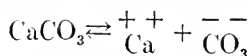
¹ Analyses performed at the Bureau of Chemistry, United States Department of Agriculture, under the direction of H. W. Wiley, chief chemist.

Besides these substances, the following were determined in spring No. 15 (Big Iron), which is not only the largest spring in the group but will serve as an example of all the other springs, since the chemical composition of all of them is so nearly alike:

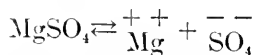
Barium.
Strontium.
Fluorine.

In reporting the results of analysis, the bases and acids are given in parts per million of the positive and negative ions, except in the case of silica, which, in the present state of our knowledge, we can only report as such, not going into the question of how much is present as the silicic acid ion and how much present as free silica. Iron and aluminum are always reported together, because of the great difficulty in separating such small amounts of the two as appear in these waters. Wherever iron and aluminum are involved in any calculation the whole is considered as iron and given an atomic weight of 56. This is doubtless practically correct, since a test of the residue from a large volume of one of the springs showed that the iron-aluminum precipitate consisted almost entirely of iron and contained aluminum, at the most, only in traces.

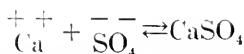
Because of the fact that these analyses will doubtless be referred to by many who have had no chemical training, the author has thought it best to combine the acids and bases in a hypothetical combination, thus reporting them as salts. That such a combination has no basis, in fact, is doubtless true, since we have every reason to believe that where various basic and acid ions are present in solution no base unites with any particular acid to the exclusion of all others, or vice versa, but that all possible combinations are formed, to at least some extent, of the various basic and acid ions present in solution. For example: Suppose we have calcium carbonate in solution. It partly dissociates into the positive and negative ions Ca and CO₃ as follows:



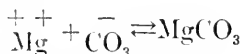
Again, if magnesium sulphate is in solution it partly dissociates as follows:



Now, if these two solutions are poured into each other, part of the calcium and sulphuric acid ions unite to form calcium sulphate, as follows:



and part of the magnesium and carbonic acid ions unite to form magnesium carbonate, as follows:



so that we have in solution not only the calcium carbonate, magnesium sulphate, and magnesium, calcium, carbonic acid, and sulphuric acid ions with which we started, but also some calcium sulphate and magnesium carbonate.

In calculating the above-mentioned hypothetical combination, sodium is joined to the nitrous and nitric acid ions; potassium to iodine and bromine; calcium to the phosphoric-acid ion and sodium to the metaboric-acid ion. Chlorine is assigned to the bases in the order NH_4 , Li, K, Na; sulphuric-acid ion in the order NH_4 , Li, K, Na, Mg, Ca, and the residual bases are joined to bicarbonic-acid ion in the order Na, Mg, Ca, Mn, Fe. In case the bicarbonic-acid ion is not present in large enough amounts to join with all the remaining bases, the residual calcium is joined to silica to form calcium silicate, and manganese and iron are calculated as Mn_3O_4 and Fe_2O_3 , respectively.

METHODS OF EXAMINATION.

Temperature.—The temperature of each spring was taken with an accurately standardized maximum thermometer on the date of the sanitary analysis of the water. Finally the temperatures of all of the springs were taken in one day. It will be noticed that these temperatures sometimes vary quite a few degrees for the same spring. This seems to be due to two causes. In the first place the temperature of the spring as it issues from the earth varies slightly from time to time; secondly, the springs sometimes have quite large basins, so that we can not get the temperature just as the water issues from the earth, but must take it as influenced by a comparatively large body of water, which in turn has been cooled to some extent by standing in the air. When these springs have recently been drained the temperature is nearly the same as where they issue from the earth, but when the basin is full the temperature is quite a few degrees lower.

Flow.—The flow of each spring was measured by observing the length of time taken to fill a vessel of known capacity from a pipe that drained the spring in question. In some cases such determinations could not be made, so the flow of the springs was estimated by comparing them with other springs of known flow. Such estimations were made by the head waterman of the reservation, Mr. Ed Hardin, who by long experience had arrived at such a point that he could come very near the correct figure.

Hydrogen sulphide.—The test for the presence of hydrogen sulphide was made both by boiling a sample of water and noticing the smell, and by passing the vapors over a piece of lead acetate paper. In a few cases, as a check, an actual determination of the hydrogen sulphide by the method given in Sutton's Volumetric Analysis was made. This is as follows:

About 0.5 c. c. of $\frac{n}{10}$ iodine was measured into a 500 c. c. flask and the water under examination run in till the color of the iodine disappeared. Five c. c. of starch water was added and $\frac{n}{10}$ iodine run in till the blue color appeared. The flask was then filled to the mark with distilled water. The amount of water actually titrated was found by subtracting the sum of iodine, starch solution, and distilled water from 500 c. c. As an excess of iodine solution was required to produce the blue color, a correction was applied by making 5 c. c. of starch solution up to 500 c. c. with distilled water and adding $\frac{n}{10}$ iodine until the color of the solution was just as blue as that in the actual determina-

tion. This figure subtracted from the first figure would give the number of c. c. of $\frac{11}{10}$ iodine used by the hydrogen sulphide. In every case tried the correction was just equal to the original figure, and in neither of the other tests was hydrogen sulphide found to be present in any of the springs.

Nitrogen and oxygen.—Nitrogen and oxygen were determined by making use of the Tiemann and Preusse modification of Reichhardt's apparatus, the description of which is here taken from Hempel's Gas Analysis (translated by L. M. Dennis, Cornell University):

This consists of two flasks, A and B (Fig. 1), each of about 1 liter capacity and connected by tubes with the gas collector C. The flask A is fitted with a perforated rubber stopper in which is inserted the glass tube *a* bent at a right angle and ending flush with the lower surface of the stopper; *a* is joined by a piece of rubber tubing to the tube *bc*, which in turn connects with the gas collector C. C is held by a clamp, has a diameter of 30 mm., is about 560 mm. long, and at the upper end is drawn out to a short, narrow tube, which can be closed with the rubber tube and pinchcock *g*. In the lower end of C is a rubber stopper with two holes through one of which the tube *bc*, projecting about 280 mm. into C, is inserted. Through the other opening passes the tube *d*, which extends only slightly beyond the stopper and connects C with the flask B. B has a double bore rubber stopper carrying the tubes *e* and *f*; *e* ends about 10 mm. above the bottom of the flask and above the stopper it is bent at a right angle and is connected with *d*. The tube *f*, which need not project below the stopper, carries a thin rubber tube X about 1 meter in length and is provided with a mouthpiece. A pinchcock for closing the rubber between *a* and *b* is also needed.

The apparatus thus arranged is made ready for a determination by filling the flask B somewhat more than half full of boiled, distilled water and removing the flask A by slipping the tube *a* out of the rubber connection; then by blowing into the rubber tube X, water is driven over from the flask B into the gas collector C and the adjoining tubes until the air is wholly displaced. The rubber tubes at *b* and *g* are now closed with pinchcocks. The flask A is then filled to the brim with distilled water, the stopper is inserted, water being thereby driven into the tube *a* and the flask is again connected with *b*, the pinchcock being opened.

The water in B is now heated to gentle boiling, and that in A is allowed to boil somewhat more rapidly. The absorbed air is thus driven out, and the gases dissolved in the water which is in A and C collect in the upper part of C, from which they are removed by occasionally opening the pinchcock at *g* and blowing into the rubber tube X.

When upon cooling the apparatus, the gases which have collected disappear, the heating of the flask A is discontinued, the pinchcock between *a* and *b* is closed and A is disconnected and emptied. The water in C and B is now entirely free from absorbed gases and air can not enter from without, because the liquid in B is kept continually boiling. The apparatus is now ready for a determination, which is made as follows: The cooled flask A, whose capacity has been previously determined, is filled with the water to be examined and the stopper is pressed in so far that the air in the tube *a* is completely driven out; *a* is then connected with *b*, care being taken that in so doing no air bubbles are inclosed. The pinchcock between *a* and *b* is opened and the water in A is heated to gentle boiling. The dissolved gases are hereby driven over into the gas collector C. Steam is formed at the same time. The heating of the flask A must be so regulated that the gas and steam evolved never drive out more than half the liquid in C, otherwise there is danger of gas bubbles entering the tubes *d* and *e* and thus escaping.

After heating for about 20 minutes the flame under A is removed. In a few minutes the steam in A and C condenses, and water passes from B to C and A. If a gas bubble is observed in A which will not disappear when the neck of A is cooled by applying a wet towel two or three times, the flask A must again be heated and cooled in the manner just described. The operation is ended when the hot liquid flows back and completely fills A.¹ The rubber tube *g* is then connected with a small piece of thermometer tube which is filled with water, and gas standing over the hot liquid in C is driven over into a modified Winkler gas burette by blowing into the tube X and opening the pinchcock *g*.

¹ It has been observed in waters rich in bicarbonates that it is nearly impossible to drive off all the CO₂ by this means, but the O and N and part of the CO₂ are driven off in the course of a half hour's boiling. Therefore the author did not continue boiling A, even though a small bubble of gas was present, more than one-half an hour.

The gases in the burette were allowed to cool for about 10 minutes, and then passed into a simple absorption pipette filled with potassium-hydrate solution (one part KOH to two parts of water). The pipette was shaken two or three times to absorb the carbon dioxide, and the residual gases passed back into the burette. The burette was allowed to stand for a few minutes and the volume of the gas read off. This gave the volume of oxygen + the volume of nitrogen. The gas was then passed into a double-absorption pipette filled with potassium pyrogallate, prepared by mixing 5 grams pyrogallie acid and 15 c. c. of water with 120 grams of potassium hydroxide and 80 c. c. of water. After being shaken with this solution for about four minutes the gas was passed back into the burette, the burette allowed to stand for a few minutes, and the reading taken. The last reading gave the number of c. c. of nitrogen present, and the difference between the first and

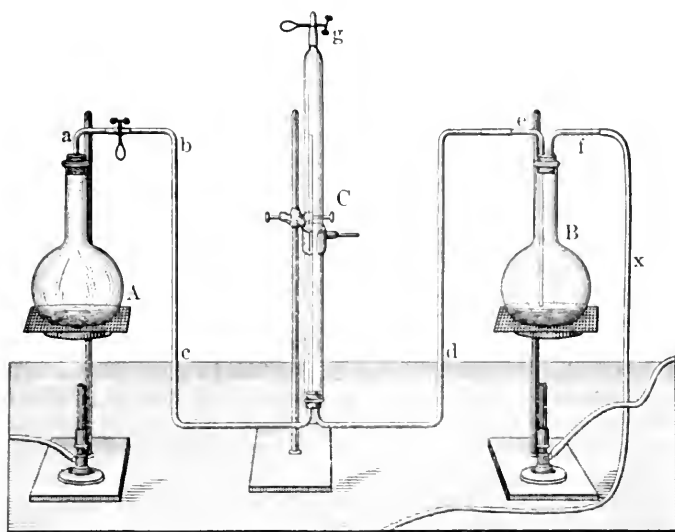


FIG. 1.

last reading, the number of c. c. of oxygen. A temperature and barometric pressure reading were also taken, to correct the gas volume to 0° C. and 760 mm. pressure. Numerous precautions as to temperature, saturation of reagents, etc., not mentioned in the above brief sketch, were taken, all of which can be found in any standard work on gas analysis.

Carbon dioxide (in excess of that necessary to form normal carbonates).—The determination of the carbon dioxide existing in water in excess of that present as normal carbonates was made by a method given in Sutton's Volumetric Analysis and designed by Pettenkofer. One hundred c. c. of the water was treated in a flask with 3 c. c. of a saturated solution of calcium chloride, 2 c. c. of a saturated solution of ammonium chloride, and 45 c. c. of a saturated solution of calcium hydroxide, whose strength had previously been determined in terms of $\frac{n}{10}$ hydrochloric acid, using lacmoid as indicator. The flask was

stoppered, the solution well mixed, and the whole set aside for 12 hours to allow the calcium carbonate to settle. At the end of this time 50 c. c. of the clear solution was drawn off in a pipette and titrated with $\frac{n}{10}$ hydrochloric acid, using lacmoid as indicator. This result

was multiplied by three and subtracted from the amount of $\frac{n}{10}$ hydrochloric acid necessary to neutralize 45 c. c. of the calcium hydroxide solution, thus giving the amount of calcium hydroxide solution that had been acted on by the carbon dioxide in terms of $\frac{n}{10}$ acid. Multiplying the number of c. c. so found by 0.0022, the weight of carbon dioxide in 100 c. c. above that necessary to form normal carbonates was found. Dividing the weight so found by the weight of 1 c. c. of carbon dioxide at 0° C. and 760 mm. pressure and multiplying the result by 10, the number of c. c. of carbon dioxide in a liter in excess of that necessary to form normal carbonates was given.

** Carbon dioxide (given off from the bicarbonates when they are evaporated to dryness).*—In making this determination the method of Cameron¹ for the "Estimation of carbonates and bicarbonates in aqueous solution" was used. By this method the amount of bicarbonic acid ion (HCO_3) was determined, and from this we could easily estimate how much of the bicarbonic acid would remain as the normal carbonate and how much be given off as carbon dioxide. The method is as follows:

To 100 c. c. of the water was first added a few drops of phenolphthalein. In case there were alkali carbonates present the usual red color would be evident. The solution was now titrated with a solution of H_2SO_4 , containing 6.758 grams to the liter, adding the H_2SO_4 solution at the rate of a drop every two or three seconds, until the red color had completely disappeared. The reading on the burette was recorded, and to the clear solution was added one drop of methylorange. A pure yellow color resulted. The titration was continued with the H_2SO_4 without refilling the burette until the change to a very slightly darker and reddish color was noted. The change was faint and required practice to detect. The reading at this point was also recorded.

The first reading recorded gives the amount of alkali carbonates present and must be multiplied by the factor 0.002979 for the result in grams of CO_3 ions.

For the number of grams of HCO_3 ions present the first recorded reading is multiplied by two and the result subtracted from the second reading, and this remainder is multiplied by the factor 0.003028. In no case were carbonates found in any of the springs by the above method, but only bicarbonates.

Having now obtained the weight of HCO_3 ions in 1,000 c. c. of water, we next calculate the weight of CO_2 given off when a like volume is evaporated to dryness, and dividing this result by the weight of 1 c. c. of carbon dioxide at 0° C. and 760 mm. pressure the number of c. c. of carbon dioxide given off from the bicarbonates is the result. Subtracting the number of c. c. of carbon dioxide given off from the

¹ Report 64 U. S. Department of Agriculture; American Chemical Journal. 23,471 (1900).

bicarbonates from the number of c. c. of carbon dioxide in excess of that necessary to form normal carbonates, we have left the number of c. c. existing in solution in a free state.

Bicarbonic acid.—The amount of bicarbonic acid present in the spring was estimated during the process of determining the amount of carbon dioxide given off from bicarbonates in the paragraph above.

It will be noticed in several of the analyses of the different springs that the amount of carbon dioxide (set free from bicarbonates on evaporating to dryness) and calculated from the bicarbonic acid does not agree with the amount of bicarbonic acid found in solution. This is because the samples for determining the carbon dioxide and bicarbonic acid were taken at widely different periods, and the amount of bicarbonic acid had evidently changed somewhat during the intervening time. This is easily explained when we remember that many of the springs are supplied from two or three different spring heads, which doubtless vary from time to time both in their amount of flow and in the amount of bicarbonic acid held in solution.

Nitric acid.—For the determination of nitric and nitrous acid, free and albuminoid ammonia, and oxygen consuming capacity the methods as given in Mason's Examination of Water were followed in all their principal details. In determining nitric acid, 100 c. c. of the spring water was treated with 2 drops of a saturated solution of sodium carbonate and evaporated to dryness on the water bath. The residue was treated with 2 c. c. of phenol sulphonic acid (made by mixing 148 c. c. of pure sulphuric acid, 12 c. c. of water, and 24 grams of phenol), a little water added, and then an excess of ammonia. The solution was transferred to a 100 c. c. Nessler jar, the volume made up to 100 c. c. with distilled water, and the depth of the yellow color compared with that produced by treating different measured amounts of standard potassium nitrate (containing 0.01 milligram of nitrogen as nitrate in each c. c.) in the same manner.

Nitrous acid.—For this determination 100 c. c. of the water was placed in a 100 c. c. Nessler jar and treated with 1 drop of concentrated hydrochloric acid. One c. c. of sulphanilic acid (containing 1 gram in each 100 c. c. of water) was then added, followed by 1 c. c. of a solution of naphthylamine hydrochloride (obtained by boiling 0.5 gram of the salt with 100 c. c. of water for 10 minutes at constant volume), and the whole well mixed. The Nessler jar was then set aside for half an hour, along with several other Nessler jars containing known amounts of a standard nitrite solution (containing 0.0001 milligram of nitrogen as nitrite in each c. c.), made up to 100 c. c. with nitrite-free water, and treated with hydrochloric acid, sulphanilic acid, and naphthylamine hydrochloride in the manner just described. By comparing the depth of pink color in the known and unknown solutions the amount of nitrite could be determined.

Free ammonia.—A large flask of about 1½-liter capacity was connected to an upright bulb condenser by means of a rather large glass tube and soft, new, rubber-stopper connections. In this was placed 5 c. c. of a saturated solution of sodium carbonate and 200 c. c. of ammonia-free water. The water was distilled off in 50 c. c. Nessler jars until no more ammonia was shown, when the jars were nesslerized. Five hundred c. c. of the water under examination was now added and

the distillation in 50 c. c. Nessler jars continued till ammonia ceased to be given off. About four or five jars were usually necessary. These jars were nesslerized and the depth of color compared with that in other jars which contained known amounts of a standard ammonium chloride solution (containing 0.01 milligram of NH_3 in each c. c.), made up to 50 c. c. with ammonia-free water and nesslerized in the same manner.

Total ammonia.—The same apparatus was used as that mentioned in the paragraph above. In it were placed 200 c. c. of distilled water and 50 c. c. of alkaline permanganate solution (prepared by dissolving 200 grams of potassium hydroxide and 8 grams of potassium permanganate in 1,250 c. c. of water and boiling the whole down to about 1 liter). The water was distilled off in 50 c. c. Nessler jars till ammonia ceased to come over. Five hundred c. c. of water under examination was now added and the distillation continued till ammonia ceased to come off. Six jars were in all cases sufficient. These jars were nesslerized and compared with nesslerized jars of known strength just as in the determination of free ammonia. From the total ammonia thus found subtract the free ammonia and the result is the albuminoid ammonia in 500 c. c. of water.

Many precautionary details of the two above methods are not given, but can be found by consulting any good book on water analysis.

Oxygen-consuming capacity.—In making this determination two solutions were first prepared: (1) A standard solution of potassium permanganate containing 0.3952 gram to the liter, each c. c. of which has 0.1 milligram of oxygen available for oxydation; and (2) a standard solution of oxalic acid containing 0.7875 gram of crystallized oxalic acid to the liter. The value of the oxalic acid in terms of the permanganate was determined by boiling 10 c. c. of oxalic-acid solution and 200 c. c. of distilled water with 10 c. c. of sulphuric acid (1-3) and titrating the fluid while boiling with the standard permanganate solution to the appearance of a pink color. In the actual determination 200 c. c. of the water in a porcelain dish was treated with 10 c. c. of sulphuric acid (1-3) and the whole brought to the boiling point. Standard permanganate was run in until the water was quite red and the boiling continued for 10 minutes, adding permanganate every now and then to keep the pink color about the same. The boiling was now stopped, 10 c. c. of oxalic acid run in, which destroyed the color, and the solution titrated with the standard permanganate to the appearance of a pink color. From the total number of c. c. of permanganate used was subtracted the number of c. c. equal to 10 c. c. of oxalic acid. The result gives the number of c. c. of permanganate required for 200 c. c. of water.

Total solids.—Measured amounts of the water were evaporated to dryness in weighed platinum dishes on the steam bath. The dishes were dried for 12 hours at the temperature of boiling water, cooled in the desiccator, and weighed. The increase in weight of the dish gives the amount of solids present in the volume of water used.

To determine chlorine, iron, and aluminum, manganese, bromine, iodine, arsenic, and boric acid large quantities of the water were evaporated to dryness after the addition of a small amount of sodium carbonate. The residue thus obtained was boiled with distilled water, transferred to a filter, and thoroughly washed with hot water. The

residue in the paper was dried and transferred to the dish in which the evaporation was made, the paper burned and added, and the whole kept for the determination of iron, aluminum, and manganese. The filtrate was made to a definite volume and aliquot portions taken to determine the constituents mentioned above other than iron, aluminum, and manganese.

Chlorine.—An aliquot portion from the above filtrate was treated with a few drops of phenolphthalein and $\frac{11}{10}$ H_2SO_4 added at the rate of a drop every few seconds until the red color had entirely disappeared, thus showing that all of the carbonates had changed to bicarbonates.¹ A few drops of potassium chromate indicator were then added and the chlorides titrated with a solution of silver nitrate each c. c. of which would precipitate 1 milligram of chlorine.

Iodine and bromine.—The qualitative tests for the presence of iodine and bromine were very much the same as those used in Fresenius. Another aliquot portion from the above filtrate was evaporated to dryness on the steam bath. Two or 3 c. c. of water were added to dissolve and soften up the residue and enough absolute alcohol added to bring the percentage of alcohol down to about 90 per cent. This was boiled and filtered and the treatment with 90 per cent alcohol repeated once or twice. Two or 3 drops of sodium hydrate solution were added to the filtrate and it was evaporated to dryness. The same process of extracting with 90 per cent alcohol was repeated on the new residue and the extract filtered off from the undissolved portion. A drop of sodium hydrate was added to the filtrate and it was evaporated to dryness. The residue was treated with a little distilled water, dilute sulphuric acid added to acid reaction, the liquid transferred to a test tube, and a little carbon disulphide added. Three or 4 drops of potassium nitrite solution were then added and the test tube shaken. The presence of iodine was shown by a pink color in the carbon bisulphide. Chlorine water was then added until the pink color due to the iodine had disappeared, then a little more chlorine water.

The presence of bromine was shown by an orange color in the carbon bisulphide.

In no case did a sample of spring water give nearly as distinct a reaction for iodine and bromine as did a known sample of water containing 0.2 milligram of both iodine and bromine, as iodides and bromides, to the liter.

An attempt was made to determine iodine and bromine quantitatively in spring No. 15 by evaporating down a large volume of water, but the attempt failed because both these elements were present in such minute traces. The method used was the same as that described by Gooch and Whitfield² and is as follows: The iodides and bromides were extracted with 90 per cent alcohol in the same manner as described above.

The alcohol extract was evaporated to dryness, acidulated with dilute sulphuric acid, mixed with a ferric sulphate solution, and distilled from a retort which was joined to a condenser sealed by a U-tube filled with water and carbon bisulphide. If a very small amount of

¹ See Cameron's paper in Amer. Chem. Journal, 23, 481, 1900. ² Bulletin 47 of U. S. Geological Survey.

iodine had been present it would have colored the carbon bisulphide and could have been titrated with sodium thiosulphate, but not enough was present.

After the distillation had been continued long enough to be sure that all iodine had been volatilized, crystals of potassium permanganate were added and the distillation continued the same as before, except that the U-tube acting as a seal was now filled with water and chloroform. The contents of the tube were treated with sodium hydroxide and zinc in a breaker and the chloride and bromide solution so formed acidified with nitric acid and precipitated with silver nitrate. The precipitate was dried and weighed. It was then dissolved in potassium cyanide and the silver precipitated by electrolysis.¹ In this way data on the weight of the combined silver chloride and bromide and the weight of the silver in same was determined. From this the weight of the bromine could be calculated, which in this case was nothing.

Arsenic acid.—An aliquot portion of the above filtrate was acidified with hydrochloric acid, the solution heated to 70° C., and a current of hydrogen sulphide passed through for several hours. In case either arsenic, copper, or lead were present they would be precipitated. No precipitation took place in any of the springs.

Boric acid.—A test for boric acid was made in the following manner: A part of the above filtrate was evaporated to dryness, treated with a cubic centimeter or two of water, and slightly acidified with hydrochloric acid. About 25 or 30 c. c. of absolute alcohol was added, the solution boiled, and filtered. This was repeated. The filtrate was made slightly alkaline with sodium hydrate and evaporated to dryness. A very little water was added, the solution slightly acidified with hydrochloric acid, and a strip of turmeric paper placed in the liquid. The whole was evaporated to dryness on the steam bath, and the heating continued until the turmeric paper had become entirely dry. In case boric acid were present the turmeric paper took on a cherry-red color.

A quantitative determination of boric acid was made in the case of two springs to serve as an example of all the other springs.

The method used was the same as that described by Gooch,² except that a slightly different form of apparatus was used.

The apparatus used by the author (Fig. 2) consisted of a round-bottomed flask with a constricted neck joined to an upright bulbed condenser by means of a glass tube slightly sloping toward the flask instead of being bent at right angles. The flask was heated by being immersed in a paraffin bath, and the distillate was received in a small flask joined to the condenser by means of a grooved cork. The method was as follows:

An aliquot portion of the above filtrate evaporated to dryness was slightly acidified with acetic acid and transferred to the round-bottomed flask, 10 c. c. of methyl alcohol was added, the flask lowered in the paraffin bath, and distilled to dryness at a temperature of 130° C. to 140° C., collecting the distillate in the flask attached to the condenser with a grooved stopper. The paraffin bath was lowered, the flask allowed to cool, and 10 c. c. more of methyl alcohol added. This was

¹ American Chemical Journal, vol. 8, p. 421.

² American Chemical Journal, vol. 9, p. 23.

then distilled over and the same process repeated six times, except that after the fourth time a couple of drops of acetic acid were added. A large platinum crucible now received about 1 gram of quicklime and was blasted until it ceased to lose weight. The constant weight was recorded and the distillate transferred to the crucible. The alcoholic solution of boric acid and the quicklime were stirred together for about 15 minutes with a platinum rod to be sure that all boric acid was fixed.

The volatile contents of the crucible were now evaporated off at a low temperature. It was found necessary to grease the edges of the crucible with vaseline to keep the solution from crawling over. After

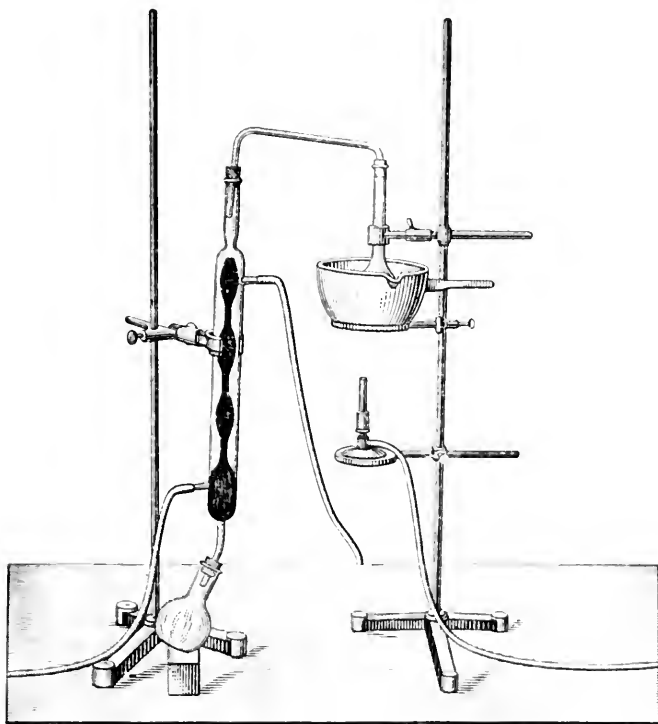


FIG. 2.

the contents of the crucible had been evaporated to dryness the crucible was fully dried in the air bath and finally blasted. The increase in weight of the crucible gives the weight of boric anhydride (B_2O_3) present.

Iron, aluminum, and manganese.—The residue spoken of previously that was reserved for the determination of iron, aluminum, and manganese was treated with hydrochloric acid and evaporated to dryness. It was thoroughly dried at about $120^\circ C.$, again taken up with water and hydrochloric acid, and filtered. The filtrate was evaporated to dryness and dried at $120^\circ C.$ It was then taken up with hydrochloric acid and water and filtered again. This filtrate was heated to the

boiling temperature, and ammonia added, a drop at a time, until it could be very faintly smelled coming off from the solution. The solution was then filtered and the precipitate well washed with hot water, burned, and weighed as Fe_2O_3 and Al_2O_3 in the ordinary manner.

The ammoniacal filtrate from above was treated with a few drops of bromine, more ammonia was then added, and the whole boiled after stirring up. The vessel was removed from the source of heat, cooled a little, and a little more bromine and ammonia added. This process repeated once or twice precipitated all the manganese as the oxide. The solution was made slightly acid with acetic acid, filtered, and washed at once with hot water. The filter and contents were burned and weighed as Mn_3O_4 . This is the method by which the iron, aluminum, and manganese were determined in springs 24 to 46, inclusive. In the first 23 springs these three elements were determined in the same portion that was used for the estimation of calcium and magnesium.

Silica.—In this determination a large quantity of water was evaporated to dryness in platinum with the occasional addition of small amounts of hydrochloric acid. After all the water had been evaporated to dryness, the dish and contents were completely dried at 120°C . The residue was taken up with hydrochloric acid and water, heated and filtered, washing the residue thoroughly with hot water. This process took out most of the silica. The filtrate was then evaporated to dryness, dried thoroughly at 120°C ., again taken up in hydrochloric acid solution by heat, and filtered. The filtrate was made to a definite volume, aliquot portions of which were used for the determination of calcium, magnesium, sulphuric acid, potassium, sodium, lithium, and phosphoric acid. The two residues were transferred to a crucible, burned and blasted in the ordinary way, and finally weighed as silica.

Calcium and magnesium.—An aliquot portion of the above filtrate was first treated with ammonia and filtered, then treated with ammonia and bromine water and filtered, and finally treated with ammonium oxalate in the usual manner. This was allowed to stand overnight, the liquid filtered off, and the precipitate dissolved in hydrochloric acid and reprecipitated with ammonia and a little extra ammonium oxalate. This was allowed to stand overnight and filtered and washed on the same paper previously used. The precipitate was dried, transferred to a crucible, burned and blasted in the ordinary way, and finally weighed as calcium oxide. The combined filtrates were evaporated to dryness in platinum and the major part of the ammonium salts driven off by the aid of heat. The residue was dissolved in dilute hydrochloric acid and filtered. The filtrate was made slightly ammoniacal, enough sodium phosphate solution added, a drop at a time, to precipitate all magnesium, and 10 c. c. of concentrated ammonia finally added, drop by drop. The beaker was covered and allowed to stand overnight, filtered, washed with dilute ammonia water, dried, blasted, and weighed as magnesium pyrophosphate.

Sulphuric acid, potassium, sodium, and lithium.—Another portion of the above filtrate was precipitated while boiling with hot, dilute barium chloride and, after standing, filtered from the precipitated barium sulphate, which was washed, dried, burned, and finally weighed in the ordinary way.

The filtrate was evaporated to dryness and taken up with water. This solution was precipitated with a solution of barium hydrate and filtered off from the insoluble magnesium hydrate. The magnesium hydrate precipitate was well washed and the combined filtrate and washings treated with ammonia, ammonium carbonate, and a little ammonium oxalate to precipitate barium and calcium. This precipitate was allowed to stand overnight, filtered off, and well washed. The filtrate and washings were evaporated to dryness on the steam bath, dried, and all of the ammonium salts driven off by gentle heat. The residue was taken up with water, filtered through a small filter, using as little wash water as possible, evaporated to a small volume, and finally again precipitated with a drop of ammonia and two to three drops of ammonium carbonate and oxalate. If any precipitate appeared, which was not usually the case, it was filtered off and the same process repeated. In any case, the solution was filtered from the magnesium hydrate that had precipitated out on concentrating the solution. The filtrate was then evaporated to dryness and all ammonium salts driven off by heating in platinum to a little below redness. The residue was taken up with a little water and filtered through a small filter, again using as little wash water as possible, and again heated in platinum to a point slightly below red heat. By this time all of the magnesia should have been removed. The residue was then taken up with a little water, filtered into a weighed platinum dish, treated with a few drops of hydrochloric acid, and evaporated to dryness. This residue was thoroughly dried, heated to a little below redness, cooled in a desiccator, and finally weighed as the combined chlorides of potassium, sodium, and lithium.

The determination of lithium was then made according to the method of Gooch¹—i. e., the combined chlorides were dissolved in water and transferred to a small beaker, where they were again evaporated nearly to dryness. About 30 c. c. of amyl alcohol was added and the contents of the beaker boiled until the temperature had risen to approximately the boiling point of the amyl alcohol, showing that all of the water had been driven off. The liquid was cooled slightly, and a drop of hydrochloric acid was added to reconvert small amounts of lithium hydrate to lithium chloride. The boiling was then continued to again drive off all water, until finally the liquid had reached a volume of about 15 c. c. The amyl alcohol was then filtered off in a weighed platinum dish and the filter washed with a little amyl alcohol that was also allowed to run into the dish. The amyl alcohol was driven off from the filter and beaker in the air bath and these two kept for the determinations of potassium and sodium. The contents of the platinum dish were evaporated to dryness, treated with a little dilute sulphuric acid, and finally burned and weighed. This gave the weight of the lithium sulphate, from which was subtracted 0.0017 gram to correct for the solubility of the sodium and potassium chlorides in the amyl alcohol. The residue was finally tested with the spectroscope for the lithium line. In every case the lithium line was found, but in no case was any lithium sulphate left after applying the correction of 0.0017 gram. The lithium was therefore reported as traces.

The contents of the beaker and filter from which the amyl alcohol

¹ American Chemical Journal, vol. 9, p. 33.

had been driven were then used for the determination of potassium and sodium. The contents of the beaker were dissolved in hot water and passed through the filter, which was thoroughly washed. The combined filtrate and washings were transferred to a porcelain dish, treated with platinum chloride solution, and evaporated nearly to dryness. The residue was treated with 80 per cent alcohol and thoroughly washed on the filter with this medium until all platinum chloride had been washed out. The filter paper was dried at the temperature of boiling water, and the residue dissolved in water and passed into a weighed platinum dish from which the water was evaporated off, the dish and contents dried at the temperature of boiling water, and finally weighed as potassium platinic chloride. An addition of 0.0008 gram of potassium chloride to the weight of this substance found is necessary.

The weight of the sodium chloride is found by subtracting the combined weights of the lithium chloride (in this case nothing) and the potassium chloride (corrected) from the total weight of the three chlorides.

Of course if the amyl alcohol in the determination of lithium above is not evaporated to exactly 15 c. c. the corrections will be different from those mentioned above.¹

Phosphoric acid.—A third aliquot portion from the filtrate mentioned above was treated with about 10 c. c. (con.) nitric acid and evaporated in a porcelain dish nearly to dryness to drive off hydrochloric acid. The residue was taken up with water and if necessary filtered. Ammonia was added to alkalinity and then nitric acid to just bring back to acidity. Some ammonium nitrate was added and the beaker heated in the water bath to 45° to 50° C. Molybdate solution was then added and the solution kept at a temperature of 45° to 50° C. for half an hour. The yellow precipitate formed at this point appeared in most cases only in traces, but in a few cases it was filtered off and washed with cold water till it was entirely free of nitric and molybdic acids. The precipitate and filter were then transferred to a beaker, a little water added, and the paper and contents thoroughly beaten into a pulp. The yellow precipitate was then dissolved by the addition of a small amount of standard potassium hydroxide solution (1 c. c. = 1 milligram of P_2O_5); phenolphthalein was added and the solution titrated with standard nitric acid solution of exactly the same strength as the alkaline solution. From the data so obtained the amount of phosphoric acid ion in the water can be calculated.² For the determination of fluorine the same method was used as described by Gooch and Whitfield.³ For the determination of barium and strontium a combination of Gooch and Whitfield's method along with another was employed. They are briefly as follows:

Fluorine.—A large quantity of water was evaporated to dryness and filtered off from the residue which was washed on the filter. The filter and contents were dried, the contents placed aside and the filter burned and the ash added to the contents. The whole was now transferred to a flask, which was so arranged as to allow a current of air to pass through any liquid that might be in the bottom, and from there

¹ For the discussion of this, see the original article already mentioned.

² Bul. 46 (revised edition), U. S. Department of Agriculture, Division of Chemistry. 1899.

³ Bul. 47, U. S. Geological Survey.

into an attached U-tube, partly filled with dilute ammonia. Concentrated sulphuric acid was added to the contents of the flask, and a current of dry air passed through the liquid, and from there into the U-tube. The flask was heated to 150°C . If any considerable amount of fluorine had been present it should have been volatilized as silicon tetrafluorid and then decomposed by the dilute ammonia in the U-tube, depositing silica in so doing. No silica appeared at this point in the spring examined. The contents of the U-tube was removed and treated with zinc oxide dissolved in ammonia, evaporated till ammonia ceased to come off, and filtered. The filtrate was treated with calcium chloride, followed by sodium carbonate in boiling solution, filtered, and washed. The residue was ignited and extracted with acetic acid. Operating in this way no residue of calcium fluoride was found.

Barium and strontium.—The residue left in the flask from the above determination was transferred to platinum, treated with enough hydrofluoric acid to volatilize all silica and with some sulphuric acid and evaporated to dryness. This treatment was repeated. The residue was fused with sodium carbonate, treated with water and a few drops of alcohol, filtered, and washed. The contents of the filter was digested with hot dilute acetic acid to dissolve barium, strontium, magnesium, and calcium carbonates, and filtered. The filtrate was then nearly neutralized with ammonia and about 50 times the weight of the combined sulphates in ammonium sulphate was added, which ammonium sulphate was dissolved in 4 times its weight of water. The whole was allowed to stand overnight. In case barium or strontium were present they would be precipitated here as the sulphates. Only a slight nonweighable opalescence appeared, however, in the spring examined. For the sake of completeness, and to be able to test the final residue with the spectroscope, the process was carried on just as in an actual determination. The precipitated sulphates were filtered and washed with a concentrated solution of ammonium sulphate till no more calcium was present in the wash water, as shown by the ammonium oxalate test. The filter was ignited and the residue evaporated to dryness with a drop or two of sulphuric acid. The combined sulphates so obtained from a very large quantity of water did not weigh over 0.5 milligram, and most of this was calcium sulphate. The extremely small residue was fused with sodium carbonate, treated with a very small quantity of water, and filtered on a very small filter paper, washing only once. Dilute hydrochloric acid was now passed through the filter and the filtrate containing any barium and strontium as the chlorides was collected in a platinum dish and evaporated to dryness. The minute residue was tested by the spectroscope for the barium and strontium lines, both of which were faintly seen.

Strontium.—This substance was determined in a separate portion. The oxide of calcium, which had been obtained by blasting the ammonium oxalate precipitate in the determination of calcium, was transferred to a small flask and dissolved in concentrated nitric acid. The acid was entirely evaporated off by means of a current of air and heating in a paraffin bath to 135°C . The flask and contents were dried at 140°C ., and the completely dried nitrates were treated with the least possible quantity of a mixture of equal parts of absolute

alcohol and ether, necessary to dissolve the calcium nitrate. The flask was corked, allowed to stand over night, and the insoluble residue, if any, filtered off on the smallest possible filter and washed with the ether-alcohol mixture. The strontium nitrate on the filter was washed with water into a platinum dish and evaporated to dryness. The dish was blasted to change the nitrate to the oxide. No increase in the weight of the dish was noticed, yet upon treating the contents of the dish with a little hydrochloric acid, evaporating nearly to dryness and testing with the spectroscope, the strontium lines were seen.

THE MEDICINAL VALUE OF THE VARIOUS SALTS AND GASES USUALLY PRESENT IN MINERAL WATERS.

CARBONATES AND BICARBONATES.

One of the most important groups of mineral waters are the alkaline waters, which are characterized by the presence, in predominating quantities, of one or more of the alkaline or alkaline earth carbonates or bicarbonates. These are the carbonates or bicarbonates of sodium, potassium, lithium, calcium, and magnesium. In case iron is present in large quantities as the bicarbonate we have a water belonging to the chalybeate class. Since these waters are alkaline they are excellent remedies in cases of sour stomach and in sick headaches which arise from acid dyspepsia. They act very markedly on the mucous membranes, increasing the flow of the gastric juice and other digestive fluids, and are consequently of use in many cases of indigestion. In conjunction with the sulphated salines they give excellent results when used in the treatment of catarrhal conditions of the stomach and intestines. Such waters correct acidity of the urine, markedly increase the flow of urine and help to dissolve uric acid deposits. They are therefore of value in cases of rheumatism and gout.

Sodium carbonate and bicarbonate.—Sodium carbonate or bicarbonate appears as a normal constituent of the blood, lymph, and nearly all secretions of the mucous membrane. Where conditions arise that cause these fluids to become acid, waters containing carbonate or bicarbonate of soda are of value in counteracting the effect. Waters containing either of these substances have been used with excellent effect in the treatment of acid dyspepsia and diabetes.

Potassium carbonate and bicarbonate.—Potassium carbonate and bicarbonate are readily soluble in water. The bicarbonate is the one usually present in mineral waters. The properties of this salt are very much the same as those of sodium bicarbonate. It increases the flow of urine and corrects acidity of the bodily fluids.

Lithium carbonate and bicarbonate.—Lithium carbonate is very sparingly soluble in water, while the bicarbonate is quite soluble. It is in the latter form that lithium is most often reported in mineral waters. This compound is most frequently used in cases of rheumatism and gout, where it forms a very soluble urate which is easily eliminated from the system.

Magnesium carbonate and bicarbonate.—Magnesium carbonate and bicarbonate are mild laxatives and are perhaps the best of all the carbonates and bicarbonates in correcting an acid condition of the stomach, and curing sick headache caused by constipation.

Calcium carbonate and bicarbonate.—Calcium is usually present in waters as the bicarbonate. Both of these compounds are quite different in their effects from the other carbonates and bicarbonates mentioned. While the others are evacuant and promote secretions, the calcium compounds constipate and decrease the secretions. Very obstinate cases of chronic diarrhea have often been cured by a sojourn at a spring rich in calcium bicarbonate.

Ferrous and manganous bicarbonates.—Neither iron nor manganese ever occur in mineral waters as the carbonate, but usually as the bicarbonate. Both of these compounds have practically the same effect. When taken internally, they are dissolved by the gastric juice and taken into the blood. They increase the appetite and the number of red blood corpuscles. It will thus be seen that such waters give excellent results when used as a tonic or in cases of anemia. Too long continued use of waters rich in bicarbonate of iron or manganese result in constipation and derangement of the digestion.

CHLORIDES.

Chlorine occurs in waters as chlorides, in combination most frequently with sodium, potassium, or lithium, and sometimes with calcium, magnesium or iron. The chlorides form the basis of that large group of mineral waters, the muriated salines.

Sodium chloride.—Sodium chloride occurs in almost all mineral springs to some slight extent, but in the muriated saline waters it occurs in large quantities as a predominating constituent. Waters containing large quantities of this substance are chiefly used in giving baths, which increase the action of the skin, and by absorption through the pores serve as a genuine tonic. Taken internally the flow of the digestive fluids is promoted and the appetite increased. Putrefactive changes in the intestines are also prevented. In large doses sodium chloride increases the flow of urine and the amount of urea present in the same.

Potassium chloride.—Potassium chloride has very much the same effect on the human system as does sodium chloride.

Lithium chloride.—Lithium chloride has practically the same effect as lithium carbonate and bicarbonate mentioned above.

Magnesium chloride.—Magnesium chloride is often used medicinally as a cathartic and to increase the flow of bile.

Calcium chloride.—Calcium chloride occurs in a number of muriated saline springs. It is used in cases of general debility as a tonic. It increases the flow of urine and perspiration and waters containing it are used in the treatment of scrofulous diseases and eczema.

Ferrous chloride.—The occurrence of ferrous chloride in mineral waters is rather rare. When present, however, it acts as a tonic and in general has the same properties as ferrous bicarbonate, already mentioned.

Ammonium chloride.—When used internally, ammonium chloride has the stimulating effect of ammonia. It is used in nervous cases as ovaralgia, sciatica, and other neuralgic disorders. In congestion of the liver its use has been beneficial. Externally it is used as a wash for ulcers and sores. It, however, seldom occurs in springs in quantities large enough to be of any value.

SULPHATES.

Sulphates are frequently found in mineral waters, and when present in large quantities give rise to that large class, the sulphated salines.

Sodium and magnesium sulphates.—Sodium and magnesium sulphates, or Glauber and Epsom salts, respectively, in small doses act as a laxative, in large doses as a cathartic. They are both valuable in increasing the flow of the intestinal fluids and in increasing the flow of urine, accompanied by an increased elimination of urea. Waters containing these salts are of great service in eliminating syphilitic, scrofulous, and malarial poisons from the system, and in eliminating mercury and other metallic poisons. Persons suffering from obesity, derangement of the liver, and Bright's disease are perhaps the most benefited by this class of waters. It must be borne in mind that such waters should be used with great care by the feeble and anæmic.

Potassium sulphate.—Potassium sulphate is frequently present in mineral waters, but in smaller quantities than the magnesium and sodium salts. Its action is practically the same as that of the other two sulphates mentioned above.

Calcium sulphate.—Calcium sulphate occurs in a great many mineral waters, and is the component that gives to them the property of permanent hardness. It is not used medicinally.

Iron and aluminum sulphates.—Iron and aluminum sulphates are usually found associated with each other in mineral waters. They are both powerful astringents. The waters containing iron sulphate are also used as tonics, but this is not nearly as good a form in which to give the iron as is the bicarbonate. Because of their astringent action, waters containing these two substances have been used with success in treating locally inflamed parts of the mucous membranes and ulcers on the outside of the body.

IODIDES.

The iodides are usually reported in mineral waters as the potassium or sodium salt. They are alterative in effect and are consequently used in the treatment of scrofula, rheumatism, and syphilis. While drinking waters containing iodides the flow of urine is very much increased and mercurial and other metallic poisons are rapidly eliminated from the system.

BROMIDES.

Bromides act as alteratives in much the same way as iodides but to not so marked an extent. They also act as sedatives.

PHOSPHATES.

Phosphates in mineral waters are usually reported in one of three forms, viz, sodium, iron, or calcium phosphate. The sodium phosphate acts as a mild laxative, the iron phosphate as a tonic, and the calcium phosphate as a medicine in those conditions of the body where lime salts are deficient, as rickets, etc.

BORATES.

Boric acid is not a very common constituent of natural waters, but is found as the sodium salt in springs of southern California in large amounts. Applied as a douche in catarrhal conditions of the uterus it is of value.

NITRATES.

Any nitric acid that may appear in a water is usually reported as sodium nitrate. This compound does not usually occur in waters to a marked extent unless they are contaminated. When present in large enough amounts it increases the flow of urine and acts as a purgative.

SILICA.

Silica appears in mineral waters both as free silica and as silicates. The medicinal value of silica has not been thoroughly investigated.

GASES.

The gases that usually occur in water are nitrogen, oxygen, carbon dioxide, and hydrogen sulphide.

Nitrogen and oxygen.—Nitrogen and oxygen are present in all waters that have come in contact with the air. On account of the limited solubility of both they can not occur in waters in very large quantities. Neither of them when present in waters has any medicinal value.

Carbon dioxide.—Carbon dioxide is present in all natural waters to some extent, but in some springs the amount is very large, thus giving rise to that large class of carbonated waters of which the Saratoga springs furnish a good example. Such waters are extremely palatable, and large quantities can be drunk without the full feeling which so often follows copious drinking of water. In moderate quantities such waters increase the flow of the saliva, promote digestion, and tend to increase the flow of urine. Obstinate cases of nausea can be often relieved by the use of small quantities of highly carbonated waters.

Hydrogen sulphide.—Hydrogen sulphide is present in many natural waters, giving to them the odor of decayed eggs, and forming that large class, the sulphureted waters. When such waters are taken internally they act as an alterative, and are consequently of value in the treatment of syphilitic diseases. They increase the activity of the intestines, kidneys, and sweat glands, so are of use in the treatment of rheumatism and gout. Excellent results have been obtained when these waters were used in treating many skin diseases and malaria.

THE MEDICAL VALUE OF THERMAL WATERS.

The curative effects of thermal waters are undoubtedly due, to a large extent, to their stimulating effects on the excretory organs of the skin and the kidneys. To fully understand this we have only to examine the routine through which a patient passes at these thermal resorts. The pores are first thoroughly opened and sweating begun by immersing the patient in hot water for from 3 to 10 minutes. The patient is then placed in the steaming room for about 5 minutes and at the same time drinks copiously of hot water. This treatment, of course, produces a profuse perspiration. After this the patient is

wrapped in blankets and passed on to a warm room for 20 to 30 minutes, where the perspiration runs off in streams. After this the patient is rubbed down and allowed to dress. A desire to urinate soon comes. Thus we see that the system is thoroughly flooded with water and washed out each day, and that tissue changes take place with wonderful rapidity. It is no wonder then that uric acid, syphilitic poisons, other materials of disease, and mercurial and other metallic poisons are soon eliminated from the system. With such effects as those mentioned above, hot baths then must be of value in the treatment of rheumatism, gout, syphilis, neuralgia, etc.

ACKNOWLEDGMENTS.

In writing the above pages on the medicinal value of mineral waters I wish to acknowledge my indebtedness to the following works:

"Mineral Springs of the United States and Canada," by G. E. Walton; "Mineral Waters of the United States and Their Therapeutic Uses," by J. K. Crook, and "Mineral Waters of Missouri, a Report of the Missouri Geological Survey," by Paul Schweitzer.

ANALYSES.

In the following pages there appears first a list giving the name and location of each spring and the date on which the sample was taken for analysis. This is followed by tables giving the temperature and flow of the springs. Then follow tables giving the detailed results of the analyses. On pages 34 and 35 is given the amount of inorganic matter present, by radicles; on pages 36 and 37 is given the per cent of total inorganic matter in solution, by radicles; on pages 38 and 39 is given the amount of water used for each determination; on pages 40 and 41 is given the amount of inorganic matter, by hypothetical combinations; on pages 42 and 43 is given the per cent of total inorganic matter present, by hypothetical combinations; on page 44 are given the gases present.

List of springs and date on which sample was taken.

1. Egg Spring, on side of Hot Springs Mountain; sample for analysis taken January 9, 1901.
2. Arsenic Spring, at base of Hot Springs Mountain under wall of Arlington Hotel; sample for analysis taken January 9, 1901.
3. Arlington Spring, on side of Hot Springs Mountain; sample for analysis taken January 9, 1901.
4. Cliff Spring, at base of Hot Springs Mountain, under wall of Arlington Hotel; sample for analysis was taken January 9, 1901.
5. Avenue Spring, on side of Hot Springs Mountain; sample for analysis was taken January 9, 1901.
6. Boiler House Spring, at base of Hot Springs Mountain, in cellar of Arlington Hotel; sample for analysis taken January 9, 1901.
7. Imperial Spring (north), on side of Hot Springs Mountain; sample for analysis taken January 9, 1901.
8. Crystal Spring, on side of Hot Springs Mountain; sample for analysis taken January 9, 1901.
9. Rector Spring, at base of Hot Springs Mountain; sample for analysis taken January 9, 1901.
10. Cave Spring, on side of Hot Springs Mountain; sample for analysis taken January 9, 1901.
11. Little Iron Spring (north), at base of Hot Springs Mountain; sample for analysis taken January 9, 1901.

12. Little Geyser Spring, on side of Hot Springs Mountain; sample for analysis taken January 9, 1901.
13. Little Iron Spring (south), at base of Hot Springs Mountain; sample for analysis taken January 9, 1901.
14. Ral Spring, on side of Hot Springs Mountain; sample for analysis taken January 9, 1901.
15. Big Iron Spring, at base of Hot Springs Mountain; sample for analysis taken January 9, 1901.
16. Imperial Spring (south), on side of Hot Springs Mountain; sample for analysis taken January 9, 1901.
17. Arsenic Spring (north), at base of Hot Springs Mountain, just back of Arlington Hotel; sample for analysis taken January 9, 1901.
18. Hitchcock Spring, at base of Hot Springs Mountain; sample for analysis taken January 9, 1901.
19. Sumpter Spring, at base of Hot Springs Mountain; sample for analysis taken January 9, 1901.
20. Superior Spring (north), on side of Hot Springs Mountain; sample for analysis taken January 9, 1901.
21. Alum Spring, at base of Hot Springs Mountain, at edge of sidewalk on Central Avenue; sample for analysis taken January 9, 1901.
22. Superior Spring (south), on side of Hot Springs Mountain; sample for analysis taken January 9, 1901.
23. Twin Spring (north), on side of Hot Springs Mountain, in the roadway; sample for analysis taken January 9, 1901.
24. Twin Spring (south), on side of Hot Springs Mountain, at side of road near Arlington Hotel site; sample for analysis taken May 19, 1901.
25. Old Hale Spring, at base of Hot Springs Mountain, under Hale bathhouse; sample for analysis taken May 19, 1901.
26. Palace Spring, at base of Hot Springs Mountain; sample for analysis taken May 19, 1901.
27. Tunnel Spring, at base of Hot Springs Mountain, in a cluster of springs; sample for analysis taken May 19, 1901.
28. Maurice Spring, at base of Hot Springs Mountain, in a cluster of springs; sample for analysis taken May 19, 1901.
29. Dripping Spring, at base of Hot Springs Mountain, flows from side of cliff; sample for analysis taken May 19, 1901.
30. Arch Spring, at base of Hot Springs Mountain, in arch of creek under Central Avenue; its level is so low that the water can not be utilized; sample for analysis taken May 19, 1901.
31. Haywood Spring, on side of Hot Springs Mountain, near road; sample for analysis taken May 19, 1901.
32. John W. Noble Spring, on side of Hot Springs Mountain; sample for analysis taken May 19, 1901.
33. Lamar Spring, on side of Hot Springs Mountain; sample for analysis taken May 19, 1901.
34. H. W. Wiley Spring, on side of Hot Springs Mountain; sample for analysis taken May 19, 1901.
35. Ed Hardin Spring, at base of Hot Springs Mountain; sample for analysis taken May 19, 1901.
36. Eisele Spring, on side of Hot Springs Mountain; sample for analysis taken May 19, 1901.
37. Stevens Springs, on side of Hot Springs Mountain; sample for analysis taken May 19, 1901.
38. Horseshoe Spring, at base of Hot Springs Mountain, under Horseshoe bathhouse; sample for analysis taken May 19, 1901.
39. Army and Navy Spring, on side of Hot Springs Mountain; sample for analysis taken May 19, 1901.
40. W. J. Little Spring, on side of Hot Springs Mountain; sample for analysis taken May 19, 1901.
41. Mud Spring, at base of Hot Springs Mountain, under free bathhouse; sample for analysis taken May 19, 1901.
42. Magnesia Spring, at base of Hot Springs Mountain, under Magnesia bathhouse; sample for analysis taken May 19, 1901.
43. Reservoir Spring, at base of Hot Springs Mountain, in back yard of superintendent's office; sample for analysis taken May 19, 1901.
44. Liver Spring (cold), on side of Hot Springs Mountain, abutting Fountain Street, between entrance to mountain roadway and superintendent's residence, now known as the "General Kelley" Spring; sample for analysis taken May 19, 1901.

45. Kidney Spring (cold), on side of Hot Springs Mountain, abutting Fountain Street, between entrance to mountain roadway and superintendent's residence, now known as the "Colonel Hamblen" Spring; sample for analysis taken May 19, 1901.
46. Fordyce Spring, at base of Hot Springs Mountain, under Palace bathhouse; sample for analysis taken May 19, 1901.
- 47.¹ Spring on the side of Hot Springs Mountain, above Arlington Hotel site; present flow very small.
- 48.¹ Spring on the side of Hot Springs Mountain, above Arlington Hotel site; present flow very small.
- 49.¹ New spring on Hot Springs Mountain, above Big Iron bathhouse site and driveway; has large flow and supplies a quantity of water for free bathhouse.
- 50.¹ New spring on the Maurice bathhouse site, discovered during the reconstruction of the Maurice bathhouse.

Temperature of springs.

| Number. | Date. | Degrees centigrade. | Degrees Fahrenheit. | Number. | Date. | Degrees centigrade. | Degrees Fahrenheit. |
|---------|---------------|---------------------|---------------------|---------|---------------|---------------------|---------------------|
| 1..... | Nov. 7, 1900 | 61.9 | 143.4 | 25..... | Dec. 10, 1900 | 62.7 | 144.8 |
| | Jan. 8, 1901 | 61.7 | 143.1 | | Jan. 8, 1901 | 62.9 | 145.2 |
| 2..... | Nov. 8, 1900 | 51.9 | 125.4 | | Dec. 11, 1900 | 63.4 | 146.1 |
| | Jan. 8, 1901 | 53.9 | 129.0 | 26..... | Jan. 8, 1901 | 61.4 | 142.5 |
| 3..... | Nov. 9, 1900 | 61.7 | 143.1 | 27..... | Dec. 12, 1900 | ..... | ..... |
| | Jan. 8, 1901 | 61.3 | 142.3 | | Jan. 8, 1901 | 51.9 | 125.4 |
| 4..... | Nov. 10, 1900 | 55.9 | 132.6 | 28..... | Dec. 14, 1900 | ..... | ..... |
| | Jan. 8, 1901 | 52.4 | 126.3 | | Jan. 8, 1901 | 59.8 | 139.6 |
| 5..... | Nov. 12, 1900 | 61.4 | 142.5 | 29..... | Dec. 12, 1900 | 57.1 | 134.8 |
| | Jan. 8, 1901 | 61.9 | 143.4 | | Jan. 8, 1901 | 57.8 | 136.0 |
| 6..... | Nov. 13, 1900 | 57.5 | 135.5 | 30..... | Dec. 15, 1900 | 53.9 | 129.0 |
| | Jan. 8, 1901 | 58.3 | 136.9 | | Jan. 8, 1901 | 51.9 | 125.4 |
| 7..... | Nov. 14, 1900 | 60.1 | 140.2 | 31..... | Dec. 19, 1900 | 51.4 | 124.5 |
| | Jan. 8, 1901 | 60.8 | 141.4 | | Jan. 8, 1901 | 51.4 | 124.5 |
| 8..... | Nov. 16, 1900 | 35.2 | 95.4 | 32..... | Dec. 17, 1900 | 46.0 | 114.8 |
| | Jan. 8, 1901 | 36.2 | 97.2 | | Jan. 8, 1901 | 46.5 | 115.7 |
| 9..... | Nov. 17, 1900 | 61.1 | 142.0 | 33..... | Dec. 18, 1900 | 48.3 | 118.9 |
| | Jan. 8, 1901 | 62.4 | 144.3 | | Jan. 8, 1901 | 49.2 | 120.6 |
| 10..... | Nov. 19, 1900 | 57.4 | 135.3 | 34..... | Dec. 20, 1900 | 47.9 | 118.2 |
| | Jan. 8, 1901 | 57.2 | 135.0 | | Jan. 8, 1901 | 47.3 | 117.1 |
| 11..... | Jan. 8, 1901 | 56.8 | 134.2 | 35..... | Dec. 21, 1900 | 39.0 | 102.2 |
| 12..... | Nov. 22, 1900 | 36.2 | 97.2 | | Jan. 8, 1901 | 43.0 | 109.4 |
| | Jan. 8, 1901 | 36.2 | 97.2 | 36..... | Dec. 22, 1900 | 48.9 | 120.0 |
| 13..... | Jan. 8, 1901 | 56.3 | 133.3 | | Jan. 8, 1901 | 48.8 | 119.8 |
| 14..... | Nov. 23, 1900 | 60.9 | 141.6 | 37..... | Dec. 26, 1900 | 52.9 | 127.2 |
| | Jan. 8, 1901 | 62.8 | 145.0 | | Jan. 8, 1901 | 52.6 | 126.7 |
| 15..... | Nov. 24, 1900 | 63.9 | 147.0 | 38..... | Dec. 27, 1900 | 58.8 | 137.8 |
| | Jan. 7, 1901 | 63.9 | 147.0 | | Jan. 8, 1901 | 59.8 | 139.6 |
| 16..... | Nov. 26, 1900 | 60.8 | 141.4 | 39..... | Dec. 28, 1900 | 61.4 | 142.5 |
| | Jan. 8, 1901 | 60.9 | 141.6 | | Jan. 8, 1901 | 61.4 | 142.5 |
| 17..... | Nov. 28, 1900 | 55.4 | 131.7 | 40..... | Dec. 31, 1900 | 48.9 | 120.0 |
| | Jan. 8, 1901 | 56.4 | 133.5 | | Jan. 8, 1901 | 48.9 | 120.0 |
| 18..... | Nov. 27, 1900 | 57.3 | 135.2 | 41..... | Dec. 29, 1900 | 46.8 | 116.2 |
| | Jan. 8, 1901 | 57.3 | 135.2 | | Jan. 8, 1901 | 48.3 | 118.9 |
| 19..... | Dec. 1, 1900 | 56.4 | 133.5 | 42..... | Jan. 2, 1901 | ..... | ..... |
| | Jan. 8, 1901 | 56.1 | 133.0 | | Jan. 8, 1901 | 58.3 | 136.9 |
| 20..... | Dec. 3, 1900 | 46.3 | 115.3 | 43..... | Jan. 3, 1901 | 46.3 | 115.3 |
| | Jan. 8, 1901 | 44.5 | 112.1 | | Jan. 8, 1901 | 46.1 | 115.0 |
| 21..... | Dec. 4, 1900 | 43.3 | 109.9 | 44..... | Jan. 4, 1901 | 8.0 | 46.4 |
| | Jan. 8, 1901 | 46.0 | 114.8 | 45..... | Jan. 8, 1901 | ..... | ..... |
| 22..... | Dec. 5, 1900 | 57.1 | 134.8 | | Jan. 5, 1901 | 13.0 | 55.4 |
| | Jan. 8, 1901 | 56.5 | 133.7 | 46..... | Jan. 8, 1901 | ..... | ..... |
| 23..... | Dec. 6, 1900 | 62.0 | 143.6 | | Jan. 6, 1901 | 51.5 | 124.7 |
| | Jan. 8, 1901 | 62.4 | 144.3 | | Jan. 8, 1901 | 51.5 | 124.7 |
| 24..... | Dec. 7, 1900 | 62.3 | 144.1 | | | | |
| | Jan. 8, 1901 | 60.3 | 140.5 | | | | |

¹ Springs 47 to 5) were not running at the time the analyses of the waters were made by Prof. Haywood.—Editor.

Flow of springs.

| Number. | Flow of springs per 24 hours. | Number. | Flow of springs per 24 hours. |
|--------------|-------------------------------------|------------|-------------------------------------|
| | <i>Gallons.</i> | | <i>Gallons.</i> |
| 1..... | 28,800 | 27..... | 800 |
| 2+17..... | 10,800 | 28..... | 121,000 |
| 3..... | 19,938 | 29..... | 2,618 |
| 4..... | 3,600 | 30..... | (³) |
| 5..... | 17,280 | 31+33..... | 7,200 |
| 6..... | 32,400 | 32..... | 28,800 |
| 7+16..... | 18,514 | 34..... | 28,800 |
| 8..... | 12,000 | 35..... | 2,400 |
| 9+11+13..... | 51,840 | 36..... | 29,600 |
| 10..... | 18,514 | 37..... | 5,700 |
| 12..... | 524 | 38..... | 140,000 |
| 14..... | 28,640 | 39..... | 35,000 |
| 15..... | 201,600 | 40..... | 24,320 |
| 18..... | 135,000 | 41..... | 124,000 |
| 19..... | 13,292 | 42..... | 50,000 |
| 20..... | 3,677 | 43..... | 1220,000 |
| 21..... | 1,152 | 44..... | 659 |
| 22..... | 1,723 | 45..... | 511 |
| 23+24..... | 10,800 | 46..... | 125,000 |
| 25..... | 135,000 | | |
| 26..... | 25,847 | Total..... | 4826,308 |

¹ Estimated.² Springs 14, 40, 41, and 43 are no longer flowing: spring 26 goes dry when water from spring 39 is being pumped by the Army and Navy Hospital.—Editor.³ Could not be estimated.⁴ Excluding the two cold springs 44 and 45.

Analyses of the waters of the Hot Springs.

[Parts per million.]

| Spring No. | Total. | SiO ₂ | SO ₄ | HCO ₃ | NO ₃ | NH ₄ | FeO | Al ₂ O ₃ | Br. | I. | Ca | Mg. | K. | Na. | Li. | NH ₄ |
|------------|----------|------------------|-----------------|------------------|-----------------|-----------------|--------|--------------------------------|--------|--------|-------|------|------|------|--------|-----------------|
| 1..... | 280,792 | 45.11 | 7.83 | 106.50 | 0.88 | Trace. | Trace. | Trace. | Trace. | Trace. | 46.09 | 4.81 | 1.65 | 4.52 | Trace. | 0.302 |
| 2..... | 272,310 | 41.48 | 8.24 | 100.50 | .44 | Trace. | Trace. | Trace. | Trace. | Trace. | 41.64 | 4.77 | 1.98 | 4.46 | Trace. | .040 |
| 3..... | 279,628 | 44.89 | 7.76 | 100.50 | Trace. | 0.007 | Trace. | Trace. | Trace. | Trace. | 46.36 | 4.88 | 1.65 | 4.52 | Trace. | .008 |
| 4..... | 271,804 | 43.55 | 8.03 | 100.50 | .44 | .0013 | Trace. | Trace. | Trace. | Trace. | 41.61 | 4.68 | 2.01 | 4.48 | Trace. | .003 |
| 5..... | 279,362 | 44.31 | 7.85 | 106.50 | .44 | .0022 | Trace. | Trace. | Trace. | Trace. | 46.58 | 4.58 | 1.65 | 4.51 | Trace. | .084 |
| 6..... | 277,563 | 44.51 | 8.50 | 103.50 | .75 | .0013 | Trace. | Trace. | Trace. | Trace. | 46.25 | 4.58 | 1.68 | 4.50 | Trace. | .025 |
| 7..... | 284,901 | 44.59 | 7.92 | 100.50 | .33 | .0041 | Trace. | Trace. | Trace. | Trace. | 47.23 | 4.99 | 1.70 | 4.57 | Trace. | .116 |
| 8..... | 280,416 | 46.28 | 7.88 | 172.00 | .22 | .0012 | Trace. | Trace. | Trace. | Trace. | 48.35 | 4.90 | 1.80 | 4.64 | Trace. | .05 |
| 9..... | 279,453 | 44.91 | 7.60 | 106.50 | .09 | .0013 | Trace. | Trace. | Trace. | Trace. | 46.18 | 4.97 | 1.68 | 4.64 | Trace. | .062 |
| 10..... | 271,626 | 44.55 | 7.73 | 100.50 | Trace. | .0016 | Trace. | Trace. | Trace. | Trace. | 45.07 | 4.94 | 1.60 | 4.37 | Trace. | .031 |
| 11..... | 275,062 | 47.44 | 8.28 | 100.50 | .18 | .0032 | Trace. | Trace. | Trace. | Trace. | 43.84 | 4.98 | 1.65 | 5.18 | Trace. | .005 |
| 12..... | 170,985 | 32.52 | 8.58 | 93.90 | .18 | .0008 | Trace. | Trace. | Trace. | Trace. | 25.89 | 3.18 | 1.31 | 3.08 | Trace. | .025 |
| 13..... | 281,642 | 46.17 | 8.35 | 106.50 | .18 | .0012 | Trace. | Trace. | Trace. | Trace. | 46.22 | 4.93 | 1.60 | 4.87 | Trace. | .013 |
| 14..... | 280,013 | 45.17 | 7.95 | 106.50 | Trace. | .0033 | Trace. | Trace. | Trace. | Trace. | 46.21 | 4.84 | 1.57 | 4.98 | Trace. | .048 |
| 15..... | 284,8016 | 45.59 | 7.84 | 108.10 | .44 | .0016 | Trace. | Trace. | Trace. | Trace. | 46.93 | 5.10 | 1.60 | 4.70 | Trace. | .040 |
| 16..... | 274,090 | 43.85 | 7.67 | 103.50 | .27 | .0010 | Trace. | Trace. | Trace. | Trace. | 45.50 | 4.81 | 1.60 | 4.61 | Trace. | .028 |
| 17..... | 275,7790 | 45.67 | 8.58 | 103.50 | .44 | .0020 | Trace. | Trace. | Trace. | Trace. | 45.40 | 4.70 | 1.88 | 4.62 | Trace. | .057 |
| 18..... | 279,4186 | 44.74 | 10.63 | 102.00 | 1.55 | .0016 | Trace. | Trace. | Trace. | Trace. | 46.04 | 4.94 | 2.01 | 4.79 | Trace. | .057 |
| 19..... | 275,1120 | 44.35 | 8.75 | 159.00 | 1.33 | .0010 | Trace. | Trace. | Trace. | Trace. | 44.72 | 4.71 | 2.00 | 4.58 | Trace. | .011 |
| 20..... | 231,0240 | 39.90 | 7.31 | 133.20 | .31 | .0010 | Trace. | Trace. | Trace. | Trace. | 37.43 | 4.23 | 1.47 | 4.40 | Trace. | .013 |
| 21..... | 280,9003 | 45.56 | 7.95 | 106.50 | Trace. | .0013 | Trace. | Trace. | Trace. | Trace. | 45.97 | 4.81 | 1.65 | 5.50 | Trace. | .069 |
| 22..... | 273,3565 | 44.79 | 8.03 | 102.00 | Trace. | .0055 | Trace. | Trace. | Trace. | Trace. | 44.73 | 4.76 | 1.64 | 4.67 | Trace. | .025 |
| 23..... | 285,1230 | 46.25 | 7.97 | 109.00 | Trace. | .0010 | Trace. | Trace. | Trace. | Trace. | 46.92 | 4.82 | 1.74 | 5.11 | Trace. | .032 |
| 24..... | 284,8858 | 46.85 | 7.51 | 108.80 | Trace. | .0008 | Trace. | Trace. | Trace. | Trace. | 46.75 | 4.92 | 1.74 | 4.78 | Trace. | .035 |
| 25..... | 282,8087 | 47.31 | 7.80 | 106.50 | Trace. | .0007 | Trace. | Trace. | Trace. | Trace. | 46.82 | 5.01 | 1.69 | 4.73 | Trace. | .028 |
| 26..... | 283,1718 | 47.86 | 7.82 | 106.50 | Trace. | .0008 | Trace. | Trace. | Trace. | Trace. | 46.75 | 4.99 | 1.74 | 4.80 | Trace. | .021 |
| 27..... | 285,7180 | 49.55 | 7.98 | 116.50 | .22 | .0010 | Trace. | Trace. | Trace. | Trace. | 49.61 | 4.95 | 1.73 | 4.66 | Trace. | .037 |
| 28..... | 280,4218 | 47.41 | 7.50 | 105.00 | .27 | .0008 | Trace. | Trace. | Trace. | Trace. | 45.47 | 4.82 | 1.76 | 4.80 | Trace. | .061 |
| 29..... | 282,0293 | 48.02 | 7.64 | 105.00 | .22 | .0003 | Trace. | Trace. | Trace. | Trace. | 45.97 | 4.80 | 1.67 | 5.09 | Trace. | .010 |
| 30..... | 273,7730 | 50.90 | 7.50 | 157.50 | .11 | .0020 | Trace. | Trace. | Trace. | Trace. | 43.00 | 4.92 | 1.72 | 4.99 | Trace. | .011 |
| 31..... | 278,1828 | 47.40 | 8.78 | 102.00 | .34 | .0008 | Trace. | Trace. | Trace. | Trace. | 45.45 | 4.72 | 1.65 | 4.69 | Trace. | .042 |
| 32..... | 274,8743 | 48.27 | 8.29 | 159.00 | .34 | .0013 | Trace. | Trace. | Trace. | Trace. | 44.75 | 4.73 | 1.72 | 4.94 | Trace. | .023 |
| 33..... | 283,1123 | 49.00 | 8.53 | 105.00 | Trace. | .0016 | Trace. | Trace. | Trace. | Trace. | 45.94 | 4.80 | 1.68 | 4.65 | Trace. | .045 |
| 34..... | 278,4105 | 46.90 | 8.08 | 102.50 | Trace. | .0015 | Trace. | Trace. | Trace. | Trace. | 45.08 | 4.73 | 1.69 | 4.54 | Trace. | .042 |
| 35..... | 280,7643 | 46.57 | 7.49 | 105.00 | 1.33 | .0013 | Trace. | Trace. | Trace. | Trace. | 46.32 | 4.79 | 1.70 | 4.65 | Trace. | .023 |

| | | | | | | | | | | | | | | | | | | | |
|----|----------|-------|-------|--------|--------|--------|--------|-----|-------|------|--------|-----|--------|-------|------|------|------|--------|------|
| 36 | 282.3637 | 48.84 | 8.71 | 163.50 | .78 | .0007 | Trace. | () | None. | 2.58 | Trace. | .19 | .11 | 46.33 | 4.92 | 1.68 | 4.70 | Trace. | .023 |
| 37 | 286.9973 | 46.65 | 15.78 | 159.10 | Trace. | .0013 | Trace. | () | None. | 2.67 | Trace. | .14 | .08 | 49.93 | 5.07 | 1.76 | 5.28 | Trace. | .036 |
| 38 | 290.5945 | 46.81 | 7.86 | 171.40 | Trace. | .0035 | Trace. | () | None. | 2.50 | Trace. | .26 | .27 | 46.61 | 5.07 | 1.60 | 5.42 | Trace. | .030 |
| 39 | 294.8740 | 50.51 | 9.41 | 163.00 | 1.33 | .0030 | Trace. | () | None. | 3.33 | Trace. | .28 | .11 | 47.11 | 5.14 | 1.93 | 5.98 | Trace. | .111 |
| 40 | 276.8590 | 45.73 | 7.76 | 163.50 | Trace. | .0010 | Trace. | () | None. | 2.67 | Trace. | .19 | Trace. | 45.43 | 4.96 | 1.59 | 5.00 | Trace. | .008 |
| 41 | 297.0996 | 52.30 | 11.95 | 168.10 | .44 | .0016 | Trace. | () | None. | 3.17 | Trace. | .29 | Trace. | 46.89 | 5.22 | 2.23 | 6.49 | Trace. | .018 |
| 42 | 286.1788 | 49.63 | 8.40 | 166.50 | .44 | .0008 | Trace. | () | None. | 2.83 | Trace. | .33 | .07 | 45.93 | 5.19 | 1.72 | 5.08 | Trace. | .038 |
| 43 | 310.0393 | 43.21 | 28.67 | 160.50 | .22 | .0113 | .53 | () | None. | 5.83 | Trace. | .41 | None. | 49.22 | 4.21 | 8.81 | 8.33 | Trace. | .008 |
| 44 | 36.459 | 12.50 | 2.30 | 12.10 | .89 | Trace. | Trace. | () | None. | 1.83 | Trace. | .34 | Trace. | 1.89 | 1.36 | .94 | 2.10 | Trace. | .009 |
| 45 | 43.7517 | 15.06 | 2.29 | 15.14 | .44 | .0007 | Trace. | () | None. | 2.00 | Trace. | .24 | Trace. | 3.79 | 1.45 | 1.02 | 2.23 | Trace. | .021 |
| 46 | 284.77 | 49.16 | 8.21 | 166.50 | () | () | .33 | () | None. | 2.50 | Trace. | .18 | .21 | 45.79 | 5.06 | 1.57 | 5.26 | Trace. | (*) |

† Small amount.

‡ Parts per million of fluorine, barium, and strontium are as follows: Fl., none; Ba., trace; Sr., trace.

§ Heavy trace.

* Not determined.

Analyses of the waters of the Hot Springs; per cent of total inorganic matter in solution.

| Spring No. | SiO ₂ | SO ₄ | HCO ₃ | NO ₃ | NH ₄ | PO ₄ | BO ₂ | AsO ₄ | Cl | Br | I | Fe & Al | Mn | Ca | Mg | K | Na | Li | NH ₄ |
|------------|------------------|-----------------|------------------|-----------------|-----------------|-----------------|-----------------|------------------|------|----|---|---------|------|-------|------|------|------|----|-----------------|
| 1..... | 16.07 | 2.79 | 58.94 | 0.32 | | | | | 0.89 | | | 0.08 | 0.09 | 16.78 | 1.72 | 0.59 | 1.62 | | 0.11 |
| 2..... | 16.34 | 3.03 | 58.95 | .17 | | | | | .92 | | | .09 | | 16.40 | 1.70 | .74 | 1.64 | | .74 |
| 3..... | 15.96 | 2.78 | 59.58 | | | | | | .90 | | | .11 | .08 | 16.60 | 1.74 | .60 | 1.63 | | .62 |
| 4..... | 16.03 | 3.17 | 59.03 | .16 | | | | | .87 | | | .13 | .08 | 16.40 | 1.72 | .74 | 1.63 | | .62 |
| 5..... | 15.84 | 2.81 | 58.62 | .15 | | | | | .86 | | | .10 | .07 | 16.67 | 1.64 | .59 | 1.62 | | .63 |
| 6..... | 16.04 | 3.06 | 58.91 | .27 | | | | | .99 | | | .07 | | 16.66 | 1.76 | .61 | 1.62 | | .61 |
| 7..... | 15.65 | 2.78 | 59.53 | .11 | | | | | .88 | | | .08 | .06 | 16.98 | 1.75 | .59 | 1.61 | | .64 |
| 8..... | 15.99 | 2.72 | 58.64 | .07 | | | 0.30 | | .80 | | | .09 | | 16.72 | 1.70 | .62 | 1.57 | | .62 |
| 9..... | 16.07 | 2.72 | 58.58 | .03 | | | | | .90 | | | .08 | .04 | 16.53 | 1.77 | .60 | 1.66 | | .62 |
| 10..... | 16.40 | 2.85 | 58.09 | | | | | | .88 | | | .08 | .08 | 16.60 | 1.82 | .59 | 1.60 | | .61 |
| 11..... | 17.24 | 3.00 | 58.35 | .07 | | | | | .99 | | | .04 | .04 | 15.95 | 1.81 | .60 | 1.88 | | .63 |
| 12..... | 19.07 | 3.96 | 55.22 | .10 | | | | | 1.35 | | | .06 | | 15.24 | 1.87 | .78 | 2.17 | | .62 |
| 13..... | 16.40 | 2.96 | 59.11 | .06 | | | 0.08 | | .91 | | | .04 | .04 | 16.41 | 1.75 | .57 | 1.73 | | .62 |
| 14..... | 16.12 | 2.84 | 59.44 | | | | | | .84 | | | .04 | .10 | 16.50 | 1.76 | .56 | 1.78 | | .62 |
| 15..... | 16.00 | 2.75 | 58.62 | .16 | | | .45 | | .89 | | | .07 | .12 | 16.48 | 1.79 | .56 | 1.67 | | .62 |
| 16..... | 15.98 | 2.79 | 59.54 | .10 | | | | | .86 | | | .03 | .10 | 16.58 | 1.75 | .58 | 1.68 | | .61 |
| 17..... | 16.46 | 3.08 | 58.88 | .15 | | | | | .81 | | | .03 | | 16.36 | 1.69 | .69 | 1.84 | | .61 |
| 18..... | 16.02 | 3.80 | 57.99 | .55 | | | | | .92 | | | .03 | | 16.48 | 1.76 | .72 | 1.71 | | .62 |
| 19..... | 16.30 | 3.21 | 58.45 | .49 | | | | | .94 | | | .03 | | 16.43 | 1.77 | .70 | 1.68 | | |
| 20..... | 17.27 | 3.16 | 57.66 | .13 | | | .06 | | 1.05 | | | .04 | .05 | 16.20 | 1.83 | .64 | 1.90 | | .61 |
| 21..... | 16.22 | 2.83 | 59.27 | | | | | | .92 | | | .03 | .04 | 16.37 | 1.72 | .59 | 1.99 | | .62 |
| 22..... | 16.39 | 2.94 | 59.26 | | | | | | .93 | | | .03 | .07 | 16.36 | 1.74 | .60 | 1.71 | | .61 |
| 23..... | 16.22 | 2.80 | 59.48 | | | | | | .85 | | | .03 | .06 | 16.46 | 1.69 | .61 | 1.79 | | .61 |
| 24..... | 16.44 | 2.74 | 59.25 | | | | | | .99 | | | .08 | .05 | 16.41 | 1.73 | .61 | 1.69 | | .61 |
| 25..... | 16.72 | 2.76 | 58.87 | | | | | | .88 | | | .07 | .10 | 16.53 | 1.77 | .60 | 1.67 | | .61 |
| 26..... | 16.90 | 2.76 | 58.80 | | | | | | .88 | | | .07 | | 16.52 | 1.76 | .61 | 1.69 | | .61 |
| 27..... | 19.31 | 3.08 | 56.70 | .09 | | | | | 1.00 | | | .06 | .05 | 15.32 | 1.91 | .67 | 1.80 | | .61 |
| 28..... | 16.91 | 2.78 | 58.85 | .10 | | | | | .92 | | | .06 | .05 | 16.21 | 1.72 | .63 | 1.74 | | .62 |
| 29..... | 17.03 | 2.71 | 58.52 | | | | .28 | | .91 | | | .08 | | 16.30 | 1.70 | .59 | 1.80 | | |
| 30..... | 18.59 | 2.74 | 57.53 | .16 | | | | | .97 | | | .04 | | 15.72 | 1.80 | .63 | 1.82 | | |
| 31..... | 17.04 | 3.16 | 58.22 | .12 | | | | | .96 | | | .07 | .09 | 16.34 | 1.70 | .60 | 1.68 | | .62 |
| 32..... | 17.56 | 3.02 | 57.84 | .12 | | | | | .91 | | | .07 | .04 | 16.28 | 1.72 | .63 | 1.80 | | .61 |
| 33..... | 17.52 | 3.01 | 58.29 | | | | | | .88 | | | .08 | .05 | 16.23 | 1.70 | .59 | 1.64 | | .61 |
| 34..... | 16.82 | 2.90 | 58.73 | | | | | | .99 | | | .09 | .01 | 16.42 | 1.70 | .61 | 1.74 | | .62 |
| 35..... | 16.38 | 2.67 | 58.77 | .47 | | | | | .86 | | | .07 | .07 | 16.49 | 1.71 | .61 | 1.66 | | .61 |

| | | | | | | | | | | | | | | | | | | | |
|---------|-------|-------|-----|-----|-----|-------|-------|-------|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| 36..... | 8,000 | 4,000 | 100 | 100 | 100 | 2,000 | 3,000 | 3,000 | 600 | 5,400 | 5,400 | 7,500 | 7,500 | 2,000 | 2,000 | 4,000 | 4,000 | 4,000 | 500 |
| 37..... | 8,000 | 4,000 | 100 | 100 | 100 | 2,000 | 3,000 | 3,000 | 600 | 5,400 | 5,400 | 9,000 | 9,000 | 2,000 | 2,000 | 4,000 | 4,000 | 4,000 | 500 |
| 38..... | 8,000 | 4,000 | 100 | 100 | 100 | 2,000 | 3,000 | 3,000 | 600 | 5,400 | 5,400 | 9,000 | 9,000 | 2,000 | 2,000 | 4,000 | 4,000 | 4,000 | 500 |
| 39..... | 8,000 | 4,000 | 100 | 100 | 100 | 2,000 | 3,000 | 3,000 | 600 | 5,400 | 5,400 | 9,000 | 9,000 | 2,000 | 2,000 | 4,000 | 4,000 | 4,000 | 500 |
| 40..... | 8,000 | 4,000 | 100 | 100 | 100 | 2,000 | 3,000 | 3,000 | 600 | 5,400 | 5,400 | 9,000 | 9,000 | 2,000 | 2,000 | 4,000 | 4,000 | 4,000 | 500 |
| 41..... | 8,000 | 4,000 | 100 | 100 | 100 | 2,000 | 3,000 | 3,000 | 600 | 5,400 | 5,400 | 9,000 | 9,000 | 2,000 | 2,000 | 4,000 | 4,000 | 4,000 | 500 |
| 42..... | 8,000 | 4,000 | 100 | 100 | 100 | 2,000 | 3,000 | 3,000 | 600 | 5,400 | 5,400 | 9,000 | 9,000 | 2,000 | 2,000 | 4,000 | 4,000 | 4,000 | 500 |
| 43..... | 8,000 | 4,000 | 100 | 100 | 100 | 2,000 | 3,000 | 3,000 | 600 | 5,400 | 5,400 | 9,000 | 9,000 | 2,000 | 2,000 | 4,000 | 4,000 | 4,000 | 500 |
| 44..... | 8,000 | 4,000 | 100 | 100 | 100 | 2,000 | 3,000 | 3,000 | 600 | 5,400 | 5,400 | 9,000 | 9,000 | 2,000 | 2,000 | 4,000 | 4,000 | 4,000 | 500 |
| 45..... | 8,000 | 4,000 | 100 | 100 | 100 | 2,000 | 3,000 | 3,000 | 600 | 5,400 | 5,400 | 9,000 | 9,000 | 2,000 | 2,000 | 4,000 | 4,000 | 4,000 | 500 |
| 46..... | 8,000 | 4,000 | 100 | 100 | 100 | 2,000 | 3,000 | 3,000 | 600 | 5,400 | 5,400 | 9,000 | 9,000 | 2,000 | 2,000 | 4,000 | 4,000 | 4,000 | 500 |

† Amount of water used for determinations of fluorine, barium, and strontium is as follows: F, 15,000; Ba, 15,000; and Sr, 6,000 c. c.

Analyses of the waters of the Hot Springs, hypothetical combinations.

[Parts per million.]

| Spring No. | Total. | NaCl. | LiCl. | KCl. | NaCl. | KBr. | KI. | K ₂ SO ₄ | Na ₂ SO ₄ | MgSO ₄ | NaBO ₂ | Ca ₃ (PO ₄) ₂ | NaNO ₂ | NaNO ₃ | Na(HCO ₃) ₂ | Mg(HCO ₃) ₂ | Ca(HCO ₃) ₂ | FeO ₂ \ Al ₂ O ₃ | Mn ₂ O ₃ | Fe(HCO ₃) ₂ | Mn(HCO ₃) ₂ | CaSO ₄ | SiO ₂ |
|------------|----------|-------|-------|------|-------|-------|-------|--------------------------------|---------------------------------|-------------------|-------------------|---|-------------------|-------------------|------------------------------------|------------------------------------|------------------------------------|---|--------------------------------|------------------------------------|------------------------------------|-------------------|------------------|
| 1... | 290.786 | 0.596 | Trace | 3.15 | 0.68 | Trace | Trace | Trace | 11.59 | 0.09 | () | Trace. | 1.20 | Trace | 0.02 | 28.96 | 186.66 | | | 0.76 | 1.16 | | 45.11 |
| 2... | 272.328 | 1.178 | Trace | 3.77 | 1.97 | Trace | Trace | Trace | 12.09 | 0.09 | () | Trace. | Trace | Trace | .80 | 28.60 | 180.79 | | | .76 | Trace. | | 44.48 |
| 3... | 279.831 | .202 | Trace | 3.15 | 1.44 | Trace | Trace | Trace | 11.49 | .31 | () | Trace. | Trace | Trace | .80 | 29.38 | 187.78 | | | 1.11 | .71 | | 44.59 |
| 4... | 271.900 | .128 | Trace | 3.83 | 1.77 | Trace | Trace | Trace | 12.40 | .31 | () | Trace. | Trace | Trace | .41 | 27.52 | 180.67 | | | .89 | .71 | | 43.35 |
| 5... | 279.3723 | .249 | Trace | 3.15 | 1.33 | Trace | Trace | Trace | 11.62 | | () | Trace. | Trace | Trace | .41 | 27.58 | 188.65 | | | | | | 41.31 |
| 6... | 277.416 | .074 | Trace | 3.20 | 1.33 | Trace | Trace | Trace | 11.41 | .99 | () | Trace. | Trace | Trace | | 28.18 | 185.90 | | | | Trace. | 1.02 | 43.98 |
| 7... | 284.8503 | .344 | Trace | 3.24 | 1.20 | Trace | Trace | Trace | 10.85 | .74 | 1.32 | Trace. | Trace | Trace | | 29.14 | 191.28 | | | 1.11 | .38 | | 41.50 |
| 8... | 280.4858 | .194 | Trace | 3.43 | 1.22 | Trace | Trace | Trace | 11.66 | | () | Trace. | Trace | Trace | .73 | 29.50 | 195.82 | | | | Trace. | | 46.28 |
| 9... | 279.676 | .181 | Trace | 3.20 | 1.42 | Trace | Trace | Trace | 11.25 | | () | Trace. | Trace | Trace | 1.57 | 29.22 | 186.45 | | | | | | 41.50 |
| 10... | 271.9644 | .092 | Trace | 3.05 | 1.44 | Trace | Trace | Trace | 11.44 | | () | Trace. | Trace | Trace | .33 | 29.74 | 179.75 | | | | 2.01 | | 43.51 |
| 11... | 275.0738 | .282 | Trace | 3.16 | 1.68 | Trace | Trace | Trace | 12.25 | | () | Trace. | Trace | Trace | 1.75 | 29.98 | 177.55 | | | .38 | .35 | | 47.41 |
| 12... | 170.0952 | .074 | Trace | 2.50 | 1.96 | Trace | Trace | Trace | 8.76 | 1.01 | () | Trace. | Trace | Trace | .44 | 17.94 | 104.53 | | | .34 | Trace. | | 32.52 |
| 13... | 281.6908 | .128 | Trace | 3.05 | 1.70 | Trace | Trace | Trace | 12.36 | | () | Trace. | Trace | Trace | .88 | 29.68 | 187.19 | | | .35 | .38 | | 40.17 |
| 14... | 290.208 | .143 | Trace | 2.89 | 1.39 | Trace | Trace | Trace | 11.76 | | () | Trace. | Trace | Trace | 2.26 | 29.14 | 186.65 | | | | Trace. | .35 | 44.90 |
| 15... | 284.8814 | .119 | Trace | 3.05 | 1.65 | Trace | Trace | Trace | 10.06 | 1.30 | 1.98 | Trace. | Trace | Trace | 2.26 | 29.14 | 186.95 | | | | 1.09 | | 43.59 |
| 16... | 274.7845 | .083 | Trace | 3.05 | 1.40 | Trace | Trace | Trace | 11.35 | | () | Trace. | Trace | Trace | 1.02 | 29.04 | 183.95 | | | | | .23 | 43.76 |
| 17... | 277.773 | .110 | Trace | 3.58 | .97 | Trace | Trace | Trace | 12.70 | | () | Trace. | Trace | Trace | 1.68 | 28.30 | 183.87 | | | .29 | Trace. | | 45.67 |
| 18... | 279.4914 | .169 | Trace | 3.83 | 1.05 | Trace | Trace | Trace | 11.75 | 3.37 | () | Trace. | Trace | Trace | .88 | 28.66 | 180.56 | | | .29 | Trace. | | 41.74 |
| 19... | 271.7045 | .033 | Trace | 3.81 | 1.12 | Trace | Trace | Trace | 11.13 | 1.54 | () | Trace. | Trace | Trace | .33 | 26.49 | 181.12 | | | .29 | Trace. | | 41.35 |
| 20... | 231.3705 | .039 | Trace | 2.80 | 1.76 | Trace | Trace | Trace | 10.82 | | () | Trace. | Trace | Trace | .33 | 25.47 | 148.35 | | | .15 | | 2.10 | 88.79 |
| 21... | 281.127 | .205 | Trace | 3.15 | 1.53 | Trace | Trace | Trace | 11.77 | | () | Trace. | Trace | Trace | 4.27 | 29.14 | 184.71 | | | | | 1.05 | 45.02 |
| 22... | 273.3223 | .074 | Trace | 3.13 | 1.47 | Trace | Trace | Trace | 11.88 | | () | Trace. | Trace | Trace | .88 | 28.66 | 180.56 | | | .29 | .58 | | 41.79 |
| 23... | 285.1865 | .095 | Trace | 3.32 | 1.30 | Trace | Trace | Trace | 11.79 | | () | Trace. | Trace | Trace | 2.84 | 29.02 | 190.03 | | | .08 | .33 | | 46.25 |
| 24... | 284.8752 | .104 | Trace | 3.31 | 1.96 | Trace | Trace | Trace | 11.56 | | () | Trace. | Trace | Trace | 1.95 | 29.02 | 189.34 | | | .70 | .48 | | 46.85 |
| 25... | 288.9840 | .083 | Trace | 3.22 | 1.50 | Trace | Trace | Trace | 11.54 | | () | Trace. | Trace | Trace | 1.46 | 30.16 | 186.20 | | | | | 2.38 | 46.08 |
| 26... | 293.5582 | .062 | Trace | 3.31 | 1.43 | Trace | Trace | Trace | 11.58 | | () | Trace. | Trace | Trace | 1.75 | 30.04 | 186.14 | | | | Trace. | 2.30 | 46.67 |
| 27... | 258.6915 | .110 | Trace | 3.29 | 1.58 | Trace | Trace | Trace | 11.81 | | () | Trace. | Trace | Trace | .30 | 29.04 | 180.42 | | | .51 | .45 | | 49.95 |
| 28... | 290.4122 | .181 | Trace | 3.36 | 1.41 | Trace | Trace | Trace | 11.34 | | () | Trace. | Trace | Trace | .67 | 28.62 | 184.15 | | | .67 | .48 | | 47.41 |
| 29... | 282.0205 | .090 | Trace | 3.18 | 1.73 | Trace | Trace | Trace | 11.30 | | () | Trace. | Trace | Trace | 2.01 | 28.90 | 181.11 | | | .70 | Trace. | | 48.02 |
| 30... | 273.7760 | .033 | Trace | 3.24 | 1.80 | Trace | Trace | Trace | 11.10 | | () | Trace. | Trace | Trace | 1.90 | 29.62 | 174.16 | | | .38 | Trace. | | 50.90 |

| | | | | | | | | | | | | | | | | | | | | | | |
|----|----------|------|-------|-------|------|-------|-------|-------|-------|-----|--------|-------|-------|------|-------|--------|-----|-----|--------|-------|-------|-------|
| 31 | 275.1802 | .125 | Trace | 3.15 | 1.80 | Trace | Trace | 11.87 | .95 | () | Trace. | .47 | .0012 | ... | 27.27 | 184.07 | 27 | ... | ... | .81 | ... | 47.40 |
| 32 | 275.2509 | .069 | Trace | 3.28 | 1.47 | Trace | Trace | 12.27 | ... | () | Trace. | .47 | .0019 | .63 | 28.47 | 178.70 | 27 | .17 | ... | 1.83 | 47.32 | |
| 33 | 283.1169 | .125 | Trace | 3.20 | 1.48 | Trace | Trace | 12.55 | .06 | () | Trace. | Trace | .0019 | ... | 28.84 | 186.08 | 31 | .70 | .48 | ... | 49.60 | |
| 34 | 278.3534 | .133 | Trace | 3.22 | 1.73 | Trace | Trace | 11.96 | ... | () | Trace. | Trace | .0024 | 1.02 | 28.47 | 184.60 | 27 | .05 | .26 | 46.75 | | |
| 35 | 280.9399 | .068 | Trace | 3.24 | 1.50 | Trace | Trace | 11.91 | .06 | () | Trace. | Trace | .0019 | ... | 28.78 | 187.23 | 27 | .28 | .26 | 46.44 | | |
| 36 | 282.6590 | .068 | Trace | 3.20 | 1.70 | Trace | Trace | 11.50 | 1.18 | () | Trace. | Trace | .0010 | ... | 28.18 | 185.90 | 27 | .15 | ... | 1.23 | 48.21 | |
| 37 | 297.1290 | .107 | Trace | 3.35 | 1.67 | Trace | Trace | 14.25 | 7.71 | () | Trace. | Trace | .0020 | ... | 21.13 | 201.81 | 20 | .11 | .29 | 46.50 | | |
| 38 | 290.0008 | .080 | Trace | 3.05 | 1.63 | Trace | Trace | 11.63 | ... | () | Trace. | Trace | .0008 | 3.68 | 30.52 | 188.77 | 23 | ... | .32 | ... | 49.81 | |
| 39 | 295.0645 | .330 | Trace | 3.68 | 2.24 | Trace | Trace | 13.93 | ... | () | Trace. | Trace | .0045 | 3.33 | 30.95 | 190.62 | 40 | .19 | ... | 12 | 50.45 | |
| 40 | 277.0755 | .024 | Trace | 3.03 | 2.06 | Trace | Trace | 11.48 | ... | () | Trace. | Trace | .0015 | 1.79 | 29.86 | 182.32 | 27 | ... | Trace. | 1.19 | 45.11 | |
| 41 | 297.3254 | .053 | Trace | 4.25 | 1.83 | Trace | Trace | 17.30 | .33 | () | Trace. | .60 | .0024 | ... | 31.00 | 188.89 | 42 | ... | Trace. | .73 | 51.92 | |
| 42 | 286.3032 | .172 | Trace | 3.58 | 1.91 | Trace | Trace | 12.43 | ... | () | Trace. | .60 | .0012 | .50 | 31.24 | 186.02 | 48 | .10 | ... | ... | 49.63 | |
| 43 | 310.1050 | .025 | Trace | 12.26 | 1.58 | Trace | Trace | 5.37 | 10.67 | () | Trace. | .30 | .0020 | ... | 12.58 | 198.00 | ... | ... | 1.39 | None | 43.21 | |
| 44 | 36.6147 | .027 | Trace | 1.79 | 1.58 | Trace | Trace | 3.55 | .13 | () | Trace. | 1.22 | Trace | ... | 8.00 | 7.21 | 49 | ... | Trace. | .32 | 12.33 | |
| 45 | 44.3231 | .062 | Trace | 1.94 | 1.72 | Trace | Trace | 3.39 | ... | () | Trace. | .60 | .0011 | 1.05 | 8.73 | 9.43 | 49 | ... | Trace. | 4.25 | 12.86 | |
| 46 | 284.89 | () | Trace | 2.90 | 1.78 | Trace | Trace | 12.15 | ... | () | .54 | () | () | 2.26 | 30.46 | 184.60 | 27 | ... | .68 | ... | 49.16 | |

1 Small amount

2 Parts per million of strontium sulphate and barium sulphate are as follows: SrSO_4 , trace; BaSO_4 , trace.

3 Heavy trace.

4 Not determined.

Analyses of the waters of the Hot Springs; per cent of total inorganic material in solution, by hypothetical combinations.

| Spring No. | NH ₄ Cl | LiCl | KCl | NaCl | KBr | KI | K ₂ SO ₄ | MgSO ₄ | NaBO ₂ | Ca ₃ (PO ₄) ₂ | NaNO ₂ | NaNO ₃ | NaHCO ₃ | Mg(HCO ₃) ₂ | Ca(HCO ₃) ₂ | Fe ₂ O ₃ | MnO ₂ | Pb(HCO ₃) ₂ | Mn(HCO ₃) ₂ | CaSiO ₃ | SiO ₂ |
|------------|--------------------|------|------|------|-----|----|--------------------------------|-------------------|-------------------|---|-------------------|-------------------|--------------------|------------------------------------|------------------------------------|--------------------------------|------------------|------------------------------------|------------------------------------|--------------------|------------------|
| 1 | 0.32 | 1.12 | 1.12 | 0.24 | | | 4.13 | | | | 0.43 | | 0.22 | 10.31 | 66.48 | | | 0.27 | 0.41 | | 18.97 |
| 2 | 0.07 | 1.38 | 1.38 | 4.44 | | | 4.44 | .03 | | | .22 | | | 10.50 | 66.39 | | | .87 | | | 16.33 |
| 3 | 0.07 | 1.13 | 1.13 | 5.11 | | | 4.11 | | | | .29 | | | 10.50 | 67.10 | 0.14 | 0.11 | .87 | .26 | | 16.04 |
| 4 | 0.05 | 1.41 | 1.41 | 4.56 | | | 4.56 | .11 | | | .22 | | | 10.33 | 66.45 | | | .41 | .25 | | 16.02 |
| 5 | 0.09 | 1.13 | 1.13 | 4.16 | | | 4.16 | | | | .22 | | | 9.87 | 67.52 | | | .32 | | | 15.86 |
| 6 | 0.03 | 1.15 | 1.15 | 4.11 | | | 4.11 | .36 | | | .37 | | | 10.16 | 67.01 | .11 | | | | 0.37 | 15.87 |
| 7 | 0.12 | 1.14 | 1.14 | 3.81 | .26 | | 3.81 | .26 | .46 | | .16 | | | 10.23 | 67.16 | | | .39 | .20 | | 15.65 |
| 8 | 0.07 | 1.18 | 1.18 | 4.03 | | | 4.03 | | | | .25 | | | 10.19 | 67.65 | .12 | | | | | 15.99 |
| 9 | 0.07 | 1.15 | 1.15 | 4.02 | | | 4.02 | | | | .01 | | | 10.70 | 66.67 | .11 | .05 | | | .11 | 15.98 |
| 10 | 0.03 | 1.12 | 1.12 | 4.21 | | | 4.21 | | | | | | .12 | 10.93 | 66.10 | .11 | | | | .71 | 16.00 |
| 11 | 0.10 | 1.15 | 1.15 | 4.45 | | | 4.45 | | | | .09 | | .03 | 10.90 | 64.55 | | | .14 | .13 | | 17.25 |
| 12 | 0.04 | 1.46 | 1.46 | 5.15 | .59 | | 5.15 | | | .12 | | | .16 | 10.56 | 61.46 | | | .20 | | | 19.13 |
| 13 | 0.04 | 1.08 | 1.08 | 4.39 | | | 4.39 | | | | .09 | | | 10.55 | 66.45 | | | .12 | .13 | | 16.39 |
| 14 | 0.05 | 1.07 | 1.07 | 4.20 | | | 4.20 | | | | | | .81 | 10.40 | 66.58 | .05 | .11 | | | .13 | 16.07 |
| 15 | 0.04 | 1.07 | 1.07 | 3.54 | .46 | | 3.54 | .46 | .66 | .03 | .22 | | | 10.23 | 66.68 | .09 | | .38 | | | 16.01 |
| 16 | 0.03 | 1.11 | 1.11 | 4.13 | | | 4.13 | | | | .13 | | .37 | 10.57 | 66.95 | .05 | .15 | | | .08 | 15.92 |
| 17 | 0.04 | 1.29 | 1.29 | 4.57 | | | 4.57 | | | | .22 | | .00 | 10.19 | 66.19 | | | .11 | | | 16.14 |
| 18 | 0.06 | 1.37 | 1.37 | 4.21 | | | 4.21 | .21 | | | .76 | | | 9.18 | 66.72 | | | .10 | | | 16.01 |
| 19 | 0.01 | 1.40 | 1.40 | 4.09 | | | 4.09 | .57 | | | .67 | | | 9.75 | 66.67 | | | .11 | | | 16.32 |
| 20 | 0.02 | 1.21 | 1.21 | 4.68 | | | 4.68 | | | .09 | .18 | | .14 | 11.01 | 64.12 | .05 | .06 | | | .91 | 16.77 |
| 21 | 0.07 | 1.12 | 1.12 | 4.18 | | | 4.18 | | | | | | 1.52 | 10.37 | 65.70 | .05 | .05 | | | .37 | 16.00 |
| 22 | 0.02 | 1.14 | 1.14 | 4.54 | | | 4.54 | | | | .35 | | .32 | 10.47 | 66.42 | | | .16 | .21 | | 16.37 |
| 23 | 0.03 | 1.16 | 1.16 | 4.13 | | | 4.13 | | | | | | .09 | 10.18 | 66.63 | .05 | .03 | | .12 | | 16.22 |
| 24 | 0.04 | 1.16 | 1.16 | 4.06 | | | 4.06 | | | | | | .33 | 10.39 | 66.47 | | | .24 | .17 | | 16.45 |
| 25 | 0.03 | 1.13 | 1.13 | 4.07 | | | 4.07 | | | | | | .51 | 10.64 | 65.75 | .10 | .14 | | | .84 | 16.26 |
| 26 | 0.03 | 1.17 | 1.17 | 4.08 | | | 4.08 | | | | | | .61 | 10.60 | 65.65 | .09 | | | | .81 | 16.46 |
| 27 | 0.04 | 1.20 | 1.20 | 4.56 | | | 4.56 | | | | .12 | | .18 | 11.52 | 62.02 | | | .20 | .17 | | 19.31 |
| 28 | 0.06 | 1.20 | 1.20 | 4.12 | | | 4.12 | | | | .13 | | .05 | 10.35 | 65.67 | | | .24 | | | 16.91 |
| 29 | 0.01 | 1.13 | 1.13 | 4.01 | | | 4.01 | | | .46 | | | .86 | 10.25 | 65.28 | | | .25 | | | 17.03 |
| 30 | 0.01 | 1.20 | 1.20 | 4.05 | | | 4.05 | | | | .22 | | .70 | 10.82 | 63.62 | | | .14 | | | 18.59 |
| 31 | 0.04 | 1.13 | 1.13 | 4.27 | .34 | | 4.27 | | | | .17 | | | 9.80 | 66.18 | .09 | | | .29 | | 17.04 |
| 32 | 0.03 | 1.19 | 1.19 | 4.46 | | | 4.46 | | | | .17 | | .34 | 10.34 | 64.93 | .09 | .06 | | | .66 | 17.20 |
| 33 | 0.04 | 1.13 | 1.13 | 4.43 | .02 | | 4.43 | | | | | | .37 | 10.19 | 65.73 | | | .25 | .17 | | 17.52 |
| 34 | 0.05 | 1.15 | 1.15 | 4.29 | | | 4.29 | | | | | | | 10.23 | 66.27 | .12 | .02 | | | .10 | 16.78 |
| 35 | 0.02 | 1.15 | 1.15 | 3.92 | .02 | | 3.92 | .02 | | | .65 | | | 10.24 | 66.65 | .10 | .10 | | | .09 | 16.35 |

Gases in the waters of the Hot Springs in Arkansas.

[Number of cubic centimeters per liter at 0° C. and 760 mm. pressure.]

| Spring No. | Nitro-gen. | Oxy-gen. | Carbon diox-ide, ¹ | Carbon diox-ide, ² | Hydro-gen sul-phide. | Spring No. | Nitro-gen. | Oxy-gen. | Carbon diox-ide, ¹ | Carbon diox-ide, ² | Hydro-gen sul-phide. |
|------------|------------|----------|-------------------------------|-------------------------------|----------------------|------------|------------------|------------------|-------------------------------|-------------------------------|----------------------|
| 1..... | 9.16 | 1.18 | 10.84 | 31.14 | None. | 26..... | 8.84 | 3.02 | 8.60 | 30.58 | None. |
| 2..... | 7.97 | 3.34 | 9.15 | 29.48 | None. | 27..... | 9.00 | 3.71 | 8.60 | 30.58 | None. |
| 3..... | 8.57 | 2.27 | 13.08 | 30.58 | None. | 28..... | 8.73 | 2.46 | 10.58 | 30.27 | None. |
| 4..... | 7.85 | 3.36 | 12.52 | 29.46 | None. | 29..... | 8.18 | 3.93 | 3.86 | 30.28 | None. |
| 5..... | 8.24 | 2.20 | 12.52 | 31.14 | None. | 30..... | 8.55 | 3.52 | 5.55 | 30.27 | None. |
| 6..... | 8.10 | 3.06 | 10.84 | 29.46 | None. | 31..... | 9.98 | 2.21 | 14.75 | 29.45 | None. |
| 7..... | 7.75 | 2.53 | 7.48 | 31.14 | None. | 32..... | 9.10 | 3.66 | 8.04 | 29.47 | None. |
| 8..... | 9.73 | 4.57 | 13.13 | 32.21 | None. | 33..... | 9.84 | 2.82 | 6.36 | 31.15 | None. |
| 9..... | 7.58 | 3.02 | 12.82 | 30.84 | None. | 34..... | 10.34 | 2.07 | 11.40 | 29.46 | None. |
| 10..... | 7.80 | 3.13 | 11.95 | 28.35 | None. | 35..... | 9.97 | 2.76 | 14.20 | 30.02 | None. |
| 11..... | 8.31 | 3.56 | 1.88 | 30.58 | None. | 36..... | 8.61 | 3.02 | 8.04 | 29.47 | None. |
| 12..... | 9.83 | 4.61 | 10.74 | 17.81 | None. | 37..... | 10.84 | 2.17 | 13.64 | 30.58 | None. |
| 13..... | 7.98 | 3.31 | 3.00 | 29.46 | None. | 38..... | 9.54 | 2.46 | 10.02 | 30.81 | None. |
| 14..... | 7.90 | 2.81 | 15.32 | 30.02 | None. | 39..... | 9.70 | 2.37 | 17.00 | 30.58 | None. |
| 15..... | 8.80 | 3.79 | 6.92 | 30.02 | None. | 40..... | 9.18 | 2.98 | 14.20 | 30.02 | None. |
| 16..... | 8.39 | 2.49 | 5.24 | 28.34 | None. | 41..... | 9.14 | 3.44 | 10.84 | 30.02 | None. |
| 17..... | 7.82 | 3.21 | 10.84 | 29.46 | None. | 42..... | 9.05 | 2.23 | 13.64 | 30.58 | None. |
| 18..... | 7.94 | 2.96 | 12.52 | 29.46 | None. | 43..... | 9.14 | 3.94 | 8.59 | 28.92 | None. |
| 19..... | 8.20 | 3.25 | 16.44 | 28.90 | None. | 44..... | 14.36 | 6.24 | 21.83 | 2.24 | None. |
| 20..... | 8.97 | 3.75 | 13.58 | 21.68 | None. | 45..... | 15.30 | 5.29 | 28.55 | 2.24 | None. |
| | | | | | | 46..... | (³) | (³) | (³) | (³) | None. |
| 21..... | 9.57 | 3.55 | 13.08 | 30.58 | None. | | | | | | |
| 22..... | 8.49 | 3.04 | 9.15 | 29.47 | None. | | | | | | |
| 23..... | 8.36 | 2.68 | 10.84 | 31.14 | None. | | | | | | |
| 24..... | 8.03 | 3.19 | 4.12 | 31.14 | None. | | | | | | |
| 25..... | 8.72 | 3.01 | 9.72 | 31.14 | None. | | | | | | |

¹ Free.² Set free from bicarbonates on evaporating to dryness.³ Not determined.

SUMMARY OF THE RESULTS OF ANALYSIS.

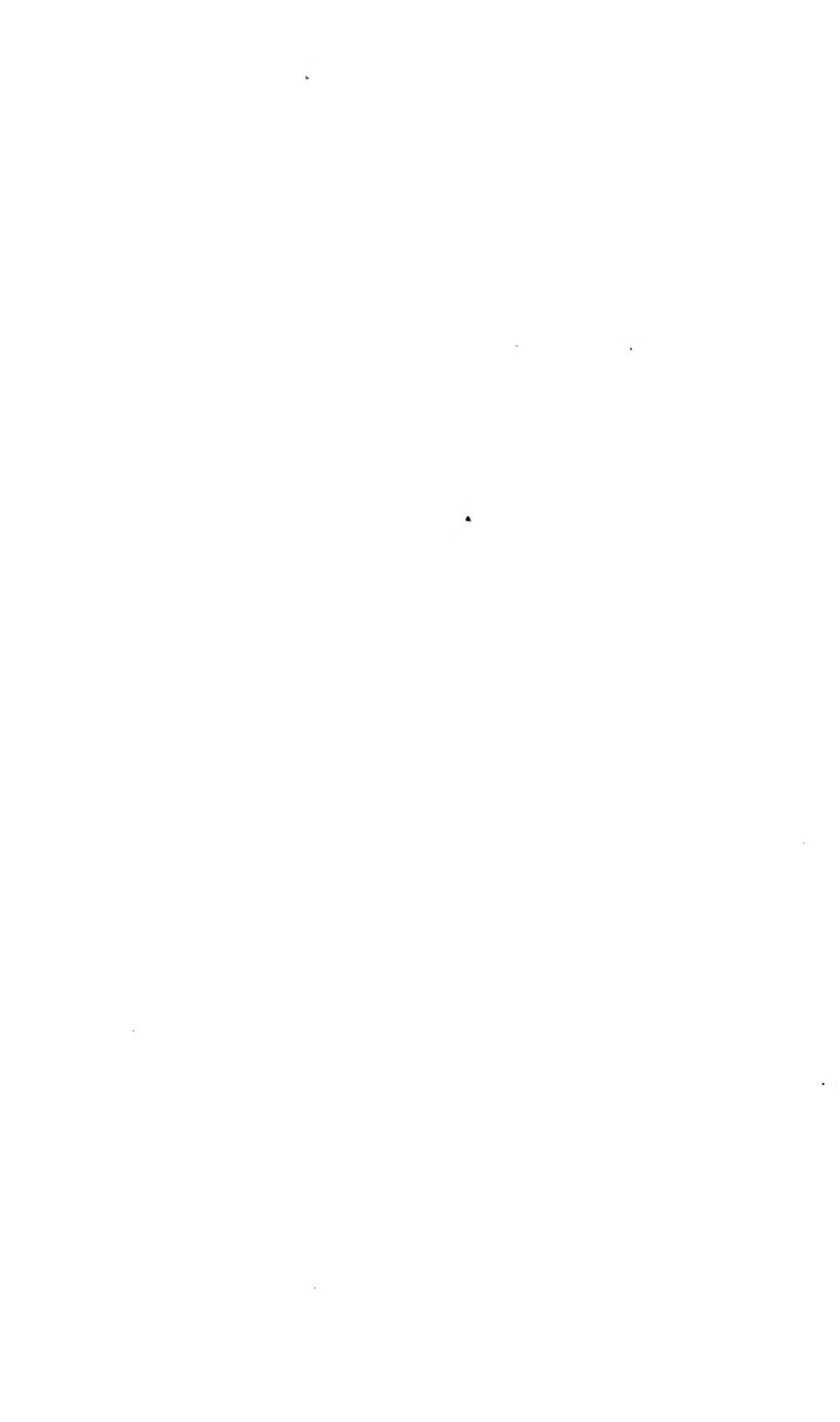
On looking over the results of analysis of the various hot springs it will be seen that the total mineral matter in solution is very nearly the same in all except springs 12, 20, 27, and 43. Spring 12 is nearly cold, and contains only 170.1 parts of mineral matter per million; spring 20 contains only 231 parts of mineral matter per million; spring 27 only 258.7 parts of mineral matter per million, while spring 43 contains the relatively large amount of 310 parts of mineral matter per million. The average amount in all the springs is between 275 and 280 parts per million, seldom falling below 270 parts per million or going above 290 parts per million.

As to the percentage composition of the mineral matter in each hot spring the results are very much the same, except in springs 12, 27, 37, 41, and 43. Spring 12 has a higher percentage of silica and sulphuric acid than the average, and a lower percentage of bicarbonic acid and calcium; spring 27, a higher percentage of silica and a lower percentage of bicarbonic acid and calcium; springs 37 and 41, a higher percentage of sulphuric acid; and spring 43 a lower percentage of silica, bicarbonic acid, and magnesium, and a much higher percentage of sulphuric acid, potassium, and sodium. Although the springs mentioned above vary to some extent from the other springs in the amount and composition of their mineral matter contained in solution, this variation is not enough, in the author's opinion, to make any difference in their medicinal value except in the cases of springs 12 and 43, the first of which is markedly weaker in medicinal constituents than the other springs, and the second of which has much more of those salts present which have a laxative effect.

From what has already been said, combined with the analyses of these waters, it will at once be seen why they have been used with such excellent results in the treatment of rheumatism, gout, syphilis, etc. We may sum up under two heads:

(1) The waters are hot, and consequently possess the medicinal value of all thermal waters, i. e., when used as a bath, in the ordinary manner followed in such cases, they stimulate the flow of sweat and urine, and thus give the system a thorough washing out each day. In this manner uric acid and syphilitic poisons are removed from the body. Mercury and other metallic poisons are also removed, in consequence of which much larger doses of mercury can be given to the patient than would otherwise be possible.

(2) All of these springs contain quite large amounts of calcium and magnesium bicarbonates. The calcium and magnesium salts of uric acid are much more soluble than the uric acid itself. Taking these two facts into consideration, it seems plausible to assume that some of the curative effects of these waters is due to the formation of the more soluble compounds, calcium and magnesium urate, which can more easily be eliminated from the system than the uric acid itself.



GEOLOGICAL SKETCH OF THE HOT SPRINGS DISTRICT, ARKANSAS.

By WALTER HARVEY WEED.

GEOGRAPHICAL LOCATION.

The Hot Springs of Arkansas are situated in the geographical center of the State, 50 miles distant from Little Rock and about 75 miles east of the Oklahoma line. The location is 600 feet above sea level and lies at the easterly base of the mountain complex known as the "Ouachita Range," the nearby peaks of which are oftentimes called the "Ozark Range," although that name really applies to the mountains in the northern part of Arkansas and the southern part of Missouri.

RELATION OF HOT SPRINGS DISTRICT TO REST OF THE STATE.

Central Arkansas consists of a low-lying, nearly level eastern portion, and a western hilly or mountainous region. The first region extends from the Mississippi River westward to Little Rock, Benton, and Malvern. The hilly country of the Ouachita Mountain system begins just west of the St. Louis, Iron Mountain & Southern Railroad, where it has a width of 36 miles, and extends westward, gradually narrowing as it approaches Oklahoma. The eastern level country is part of the Tertiary Mississippi Valley region. The western hilly country consists of a central complex of hills, flanked by sharp spurs and ridges, which extend outward into a much lower country of slight relief. This hilly country is dignified by the name of the "Ouachita Mountain system," the ridges rising gradually in elevation westward. Near the Oklahoma line the general level of the intermontane plain is 1,000 feet above tide and the crests of some of the ridges attain elevations above 2,500 feet. Near Hot Springs the mountain area seldom attains an elevation of more than 1,200 feet above the sea, or 600 feet above the surrounding country, yet, when seen from the lower country about it the hills rise so abruptly that they appear to deserve their designation. The mountains near the Hot Springs are particularly impressive, and the local summits have received special designations, as "West Mountain," "Indian Mountain," etc. These mountains have been grouped together by some writers under the name of the "Ozark system," but they have been more fittingly christened the "Zigzag" Range by Prof. Branner, of the State geological survey. This range has an extreme length of 25 miles and a width of 6 to 8 miles. The general trend of the ridges is almost at right angles to the system. These ridges are narrow and sharp, with a height of 500 to 600 feet, and they are particularly numerous in the vicinity of the Hot Springs.

TOPOGRAPHY.

The Hot Springs are situated in a valley between two wooded, rocky ridges known as "West Mountain" and "Hot Springs Mountain." The water issues from vents in the old and gray hot-spring deposit, or tufa, that covers the basal slopes of Hot Springs Mountain east of Hot Springs Creek. This location is on the outer border of the mountain system. To the east the country falls away gently to the Ouachita River, and the city of Hot Springs has been built partly in the ravine and the intermontane basin to the north and partly in the eroded plateau lying south of the springs and outside of the mountain area. The mountain slopes are rocky, and are often ribbed with abrupt cliffs and rugged ledges with extensive slopes of talus. They are generally thickly mantled with a heavy forest growth of oak, pine, chestnut, and other common forest trees, and they support a more or less abundant undergrowth. The ravines are generally narrow and the streams swift running, but good exposures of the underlying rocks are seldom seen, owing to the thick forest that covers the slopes. There is an evident relation between the hard rocks and the hills and between the softer rocks and the valleys, although the streams do not accord with any definite geological structure, but flow in synclines, in eroded anticlines, and across the strike of the beds as well. Several gaps indicate old and now abandoned stream courses and show a prolonged period of adjustment, in which the streams shifted several times before reaching their present position. Although the springs are on the borders of these mountains, this location is not wholly outside of the mountain area, since the Trapp Mountain Range lies south of the Ouachita River, so that the springs are on the north side of a synclinal basin that forms an embayment between the main Ouachita system and a small east-and-west spur on the south. The region is well watered and well drained. In the immediate vicinity of Hot Springs the Hot Springs Creek and Gulpha Creek, both of which flow into the Ouachita River, drain the entire region, the former stream flowing due south and reaching the river 4 miles below the city.

The lower country near the springs, upon which a considerable part of the city is built, is a dissected plain in which broad plateau levels alternate with shallow drainage courses that are tributary to Hot Springs Creek.

The climate of the region is a mild one, lacking both the extreme heat of summer and the cold of winter. In the summer months the air is tempered by the breezes from the mountains, and in winter the average temperature is very slightly below that which prevails at New Orleans and other southern cities. Flowers and shrubs of semitropical character grow in the open air, but the occasional frosts of winter are so sharp that a strictly semitropical vegetation will not exist.

ROCKS OF THE DISTRICT.

The rocks seen about the Hot Springs are chiefly of sedimentary origin and were formed beneath the waters of a Paleozoic sea. They occur in well-defined formations, which were folded when the mountains of the region were formed by the compressive stresses of earth movements, and these folds have subsequently been eroded by ordi-

nary atmospheric agencies. These rocks are cut by a few narrow, insignificant dikes of igneous rock, which are supposedly connected with the large masses of granite and other igneous rocks now seen at Magnet Cove and Potash Sulphur Springs. In addition to the rocks mentioned there is a considerable area of dark-gray and porous travertine, or calcareous tufa, formed by the Hot Springs.

The sedimentary rocks seen in the vicinity of the Hot Springs consist of shales, sandstones, a few beds of impure limestone, and the rock called novaculite. This last-named rock, of which the well-known Arkansas whetstones are made, is the most conspicuous and important rock in the locality. It is the typical rock of central Arkansas, and, though found over a large area, the material pure enough to be used for whetstones is confined to the vicinity of the Hot Springs. It is this rock that has, by reason of its hardness and its resistance to erosion, made the mountains about the springs, and it forms the cliffs and prominent ledges seen in the district. The bedded rocks form a series shown in the following table, in which the youngest beds are placed at the top of the column and the oldest strata at the bottom.

| Geological age. | Thickness of beds. | Character of rock. |
|---------------------|--------------------|--|
| | <i>Fed.</i> | |
| Carboniferous..... | 200 | Shales; gray or black graphitic shales with fragments of plant remains, red and yellow colored when altered. |
| | | Sandstone, impure and clayey, with softer layers alternating with softer material. |
| | 250 | Quartzose sandstones, passing at times into conglomerates and well exposed along the basal slopes of Hot Springs Mountain. |
| Lower Silurian..... | 12 | Novaculite breccia. |
| | 5 | Impure novaculite, with iron and manganese. |
| | 100 | Novaculite in thick and thin beds, with some layers of siliceous shales. |
| | 75 | Sandstone passing into novaculite. |
| | 38 | Shale, siliceous, and passing into novaculite. |
| | 200 | Massive novaculite, from which whetstone is taken. |
| | 230 | Shale, siliceous, with thin layers of novaculite. |
| | | (Impure novaculite.) |
| | 200 | Shales, red and green and gray, with siliceous layers. |
| | | Shales, black, and carrying fossil remains (graptolites). |
| | 200 | Limestone, thinly bedded, blue, and generally argillaceous. |
| | | Sandstones. |

THE ROCK STRUCTURE.

Near the Hot Springs these rocks have been compressed into great folds which now form the mountains, and this compression is so great that the folds have been pushed over, or overturned, and in the gorge of Hot Springs Creek the section now exposed shows the younger beds resting beneath the older ones. In addition to this there has been some faulting in Indian Mountain, by which an overthrust has pushed up the older beds over younger ones. For this reason the section, as given above, is not always easily made out, but it can be seen in the slopes of West Mountain, although, as will be noted there, the younger beds lie below the older and the rocks have a dip of from 25° to 70° . The Carboniferous shales, which are the youngest rocks of the district, are well exposed on Malvern Avenue near the Park Hotel, where the olive-colored, sandy shales have been found to contain plant stems and fragments of fern fronds. The shales are rarely indurated enough to form slates, though a few quarries have been opened in them and

slate of a poor quality extracted. Where the shales are slightly altered they are sometimes valuable for brick and terra-cotta burning, though most of the clay used for that purpose is derived from the disintegrated material washed into the creek bottoms.

The sandstones are of variable texture and composition. The coarser-grained rocks are nearly pure quartzose sand, but the intermediate beds are quite clayey. The chief sandstone horizon seen at the springs is the one lying just above the novaculites, and this rock is the one which is so prominent on Hot Springs Mountain and West Mountain.

The novaculites are the most interesting rocks of the region. They consist of nearly pure silica, containing less than one-half of 1 per cent of other material. The rock is very dense, homogeneous, of a cream or white color, and fine grained, resembling in appearance the finest Carrara marble. These rocks are used for whetstones, the finer-grained form being called Arkansas stone and the coarser-grained rock the Ouachita stone. This material has a marked conchoidal fracture and resembles chert in its general appearance, although, as will be shown later, this appearance is purely a superficial one and the material differs markedly from chert in its origin and composition. Although brittle and lacking the toughness of chert, it was extensively used by the Indians, who quarried it by building fires upon the outcrops until the stones were heated and then quenching the fire with water, thus chilling the rock and causing it to split and spall into fragments which were easily removed. In this condition it was readily chipped by the use of round stone hammers, great quantities of which have been found by the early settlers and which the writer has seen at some of the more remote quarries. The rock is finely jointed, and in quarry faces this jointing is more conspicuous than the bedding planes. These phenomena may be well observed in almost any of the excavations seen along the main street above the Government reservation. The finer-grained material seldom forms good outcrops because of this jointing and also because the rock contains a small amount of water, which, when frozen during the frosts of winter, shatters the stone and covers the outcrop with fine débris. This débris is extensively used as a road material, and wherever applied forms a most excellent surface.

The novaculite formation is from 500 to 600 feet in thickness, which includes some flinty shales, some soft shales, and some sandstones. The novaculites proper are prominent members of this formation and occur in beds a few inches to 12 or 15 feet thick. When these beds are less than 4 inches thick the rocks lose the novaculite character, and are more like flinty shales. When examined under the microscope the rock is found to present a very uniform appearance, and to consist of extremely minute interlocking grains of cryptoerystalline silica. Chemical tests show that this silica is quartz and not amorphous silica. Thin sections also disclose the presence of numerous cavities in the rock quarried for whetstones. These cavities have been found to present a rhomboidal outline, and they correspond in form and position to included patches of calcite found in the same rock where the bed passes beneath the creek levels. It has been assumed that these cavities are formed by the dissolution and removal of the calcite, and as the material from beneath the water level is of slight value as a whetstone it has been reasoned that the abrasive qualities of the

Arkansas stone are due to the presence of these calcite cavities. The origin of the rock has been the subject of considerable speculation from the earliest times to the present. It has been commonly asserted that it is a very fine-grained sandstone which has been indurated and altered by hot-spring action. This explanation is not adequate, however, since the same beds are exposed on the flanks of the Ouachita Mountain system for a total length of several hundred miles. Moreover, the character of the grains does not permit of the assumption that they were originally rounded and that the spaces between have been filled by a secondary deposition of silica, as is commonly the case with many quartzites. The writer's belief is that the evidence supports the opinion that the rocks were formed as a chemical precipitate in the deep seas of a Silurian ocean, and that comparatively little alteration beyond induration has taken place. Such a theory seems to accord very well with the chemical and physical nature of the rock and with the facts now known in regard to the origin of some of the early geological sediments.

IGNEOUS ROCKS.

Besides the sedimentary rocks just noted there are four narrow dikes of igneous rock about one-half mile south of the mountain borders and near the city limits. These rocks are dark-colored mica traps, a form of rock called "ouchatite." They are chiefly interesting because they show that there was some deep-seated body of molten material from which the dike fissures were supplied. Small dikes are found north of the city, east of the city, and in considerable abundance about Potash Sulphur Springs and at Magnet Cove. These dikes have a generally ESE.-WNW. direction, showing that the fissures are parallel to the mountain sides. They are from 1 to 4 feet wide and are generally much altered, so that the outcrop is inconspicuous, or is covered by vegetation, and when the rock is broken black mica in small flakes is the only mineral seen.

FOSSILS.

The age of the sedimentary rocks is determined by the fossil remains found in them. The black shales which underlie the novaculites contain remains of a curious hydrozoa. These fossil remains are known as *graptolites*, and the forms identified at the Hot Springs belong to the upper part of the Lower Silurian age (Trenton and Utica). New types of these fossils peculiar to the Hot Springs are illustrated in the Novaculite report issued by the Arkansas geological survey. Besides these curious forms, a few shell remains (*brachiopods* and *lamellibranchs*), corals, and worm trails have been found. The *graptolites* occur on the north side of the hill on a small stream drainage on the west side of the continuation of Park Avenue. They are also seen in a very black shale forming the bluff on the west side of Park Avenue above the Hotel Hay and below the Barnes House. Similar fossils also occur on Whittington Avenue, one-fourth of a mile above the head of Central Avenue, at a point where the creek crosses the street.

Plant remains of Lower Carboniferous age have been found in the shales exposed in the excavation for a cellar on the western side of Malvern Avenue, 100 feet north of the Park Hotel. The shales are

varicolored, brown, red, gray, and black, but the fossils occur in the olive-colored, sandy shales. Similar fossils were also found in Ouachita Avenue at the Hot Springs.

OCCURRENCE OF THE HOT SPRINGS.

The hot waters issue from the base and lower portion of the slopes east of the valley. This area is a narrow strip, a few hundred feet wide and a quarter of a mile long. In its general aspect this area is distinguished from the rest of the mountain by its patches of barren gray tufa, the old hot-spring deposit, and the absence of forest growth. From the descriptions given by earlier writers it is evident that this difference in appearance and vegetation was formerly very marked. To-day the springs are all covered, and mostly concealed beneath turf and shrubbery. The old tufa deposit is in large part covered by soil and plants. The creek is arched over and sidewalks and roadways are built on it. The space between creek and hillside is covered by the bathing establishments, which, in many instances, are built directly over large springs.

The landscape gardener has modified the old slopes, filled up the gullies, and built roads and footpaths, until the hot-spring area is a beautiful park and a fitting setting for the springs.

The springs occur at the southwest end or "nose" of Hot Springs Mountain. There is nothing unusual or remarkable in this topographic position, for it accords with that of many other springs of the region—as, for example, Bonanza Springs and Big Chalybeate of the plate.

It is difficult for the average visitor of to-day to form an idea of the natural appearance of the springs. The larger springs formerly issued abruptly from the tufa slopes and did not possess the bowls and basins seen at the Mammoth Hot Springs of the Yellowstone. An artificial cutting made into the mound of the Cave Spring shows a section of the hot-spring deposit, and if the door be opened the waters will be seen flowing into the basin cut to collect them, and depositing creamy alabaster-like tufa, and the brilliant emerald-green tufa, whose color is due to the growth of hot-water algæ. Many of the smaller springs are mere oozes, with no well-defined channel. A considerable number of these are gathered into one reservoir at the base of the tufa bluff between the Arlington Hotel and the Superior Bath House. Another spring is seen near the Hale Bath House, where it issues from a cavity in the tufa and flows into a basin. There is a constant flow from the tufa wall back of this masonry platform, forming the dripping spring, where thousands of visitors daily drink hot water direct from the rock. At this place also the green algaous growth may be seen.

HOT SPRING TUFFA DEPOSIT.

As already noted, the hot-spring area is characterized by a deposit of calcareous tufa, or travertine, formed by the hot waters, and covering not only a large part of the mountain slope about the existing hot springs, but also extending westward to the Happy Hollow Ravine and occurring far above any existing springs in the slope above the band stand. Tufa deposits are common about both hot and cold water springs whose waters carry alkaline-earth bicarbonates in solution.

Such materials are precipitated when the carbon dioxide of the waters escapes upon exposure of the water to the atmosphere. At the Arkansas Hot Springs only moderate quantities of the alkaline earths are in solution in the waters, yet they are sufficient to coat the hot-water pipes and to fill wooden troughs used to conduct the waters. In the Cave Spring and at the Dripping Spring the tufa may be seen now forming. It is therefore not certain that the waters which formed the great tufa deposits of the place were any richer in calcium than those of to-day. This tufa is seen in its natural state at many places about the springs, but is particularly well seen at the Cave Spring back of the Arlington Hotel. It is of a gray color, and porous texture on the surface, but when quarried is pure white, compact, and crystalline.

This tufa consists almost wholly of carbonate of lime, carrying very small and varying amounts of manganese (oxide) and iron oxide. The manganese is frequently prominent as a black powder, or occurs in blackish layers through the rock. The analysis made for Owen in 1859 of the material deposited in the pipe accords so exactly with that of the deposit now forming that it is reproduced.

Analysis of hot-spring tufa formed in pipes carrying hot water to bath houses.

| | Per cent. |
|-----------------------------|-----------|
| Carbonate of lime..... | 92.620 |
| Sulphate of lime..... | .085 |
| Carbonate of magnesia..... | 3.060 |
| Carbonate of iron..... | .210 |
| Carbonate of manganese..... | .190 |
| Potassa..... | .107 |
| Silica..... | .119 |
| Total..... | 99.391 |

In the Cave Spring the freshly deposited tufa is tinted orange by the algae that live in hot water, and green by the species that flourish at slightly lower temperatures. These colors are purely vegetable and disappear if the deposit be heated.

This tufa deposit covers an area of approximately 20 acres, and varies from a few inches to 6 or 8 feet in thickness. Its occurrence shows that some of the springs formerly flowed to the west, and that the waters covered a larger area than at present.

The broad area covered by the tufa does not mean that the hot waters covered this entire area at any one time, for the algous growth described as filling the hot-water streams causes a filling up of the channel and a diversion of the water to a different place. In two instances the waters built up mounds about the springs. The most noticeable of these is that of the Cave Spring, which has been artificially breached in the development of a larger water supply from the spring. Above the music pavilion another area of tufa indicates the former presence of springs at a level higher than any now existing.

The thickness of the tufa deposit is likely to be overestimated, as it covers steep slopes and even cliff faces.

The earliest description of the place tells of its forming overhanging masses alongside the creek, whose flood waters swept away its support. The natural exposures of conglomerate and sandstone outcropping near the pavilion show that the tufa is there underlain by hard rock. Farther west, however, the tufa overlies soft, shaly rocks, which have been digested by the hot waters and vapors for so long a

time that the material is as soft as ashes, and in the development of new water supplies near Spring No. 1 a pipe was driven 38 feet down into this material. Immediately beneath the tufa there is a breccia of novaculite sandstone or shale fragments cemented by iron oxide, manganese oxide, and carbonate of lime. This is seen under the tufa at the Cave Spring and at the Dripping Spring. It merely represents the old hillside debris cemented by the hot-water deposit and material deposited later beneath the tufa mantle.

Vegetation of tufa area.—The tufa area is described by all earlier writers as being distinguished from the adjacent slope by its peculiar vegetation. In the improvement of the reservation this distinction has been largely obliterated, as flowers and shrubs have been freely planted. The tufa cliffs and rougher exposures show, however, the limestone-loving ferns *Cheilanthes alabamensis* Kunze and *Adiantum capillus-veneris* L., which occur nowhere else in this region. Owen mentions these ferns especially, besides numerous peculiar mosses and algae, and the stonecrop, sage, lobelia, and senna as characteristic of the tufa area.

GEOLOGICAL RELATIONS OF THE HOT SPRINGS.

In the geological sketch already given the rocks from which the hot waters issue are described as sandstones and shales of Lower Silurian age, occurring in sharply compressed folds. The hot waters issue from the sandstones seen well exposed back of the superintendent's office and near the music pavilion, and from the overlying shales in the area west of the pavilion. These rocks form part of a steeply dipping anticline plunging beneath the surface toward the southwest. It may be compared to the partly buried prow of an upturned boat. The rocks arch around the mountain slopes, the different beds being revealed very much as the scales of an onion bulb are exposed when it is partly cut into. While the rocks are flexed into this great curve, the great and thick beds of hard sandstone and conglomerate were cracked while being flexed, and little slips and breaks occur. The smaller cracks form a network of fractures, which in some places are seen to be filled with white quartz. The principal springs are arranged along a line running about NNE., or parallel to the axis of the fold forming Hot Springs Mountain. This line is believed to be a fissure corresponding to a fracture of the northwest fold, a fault fissure. Springs are common along such fractures in the novaculite region of Arkansas, and there is no reason to believe there is anything unusual in this one. The source of heat is discussed elsewhere.

ARE THE HOT SPRINGS DYING?

The question whether the hot springs are changing in character and will eventually either cease flowing or become cold springs is of both popular and scientific interest. The evidence seems to show that there is a very small decrease in temperature since they were first examined, now nearly a century ago. The temperature recorded by Dunbar and Hunter in 1804 for the larger spring was 150° F., and another had a temperature of 154°. In 1859 the springs were carefully examined by David Dale Owen, State geologist. A more accurate map was published by William Glasgow, jr., in 1860 from careful instrumental surveys, together with records of temperature and outflow.

Since then many changes have been made about the springs, all of which have been dug out and inclosed in masonry arches, with the consolidation of two or more springs into one in some instances, the development of new outflows by digging wells or sinking pipes, and the drying up of adjacent natural outflows. For these reasons all the springs now existing can not be positively identified with those shown on the earlier maps, but a majority of them are so correlated without doubt.

Temperatures.—The comparison of the old records mentioned with those recently made shows that the highest temperature known to-day is 147° F., as against 154° in 1804, and 150° by Glasgow and 148° by Owen in 1860. In a number of springs there is a decline of 2° since the latter date. Such a slight difference might, however, be due to differences in the manner or place of taking the temperatures, or the instruments used in the earlier years may not have been accurate. It is noteworthy that Owen's highest temperature, taken in 1859 with a standardized thermometer, was 148° , and that recorded now is 147° . In other words, the temperature is decreasing so slowly that the change is almost imperceptible in half a century. In one instance, that of the Alum spring, there is a very marked decrease in temperature, and as this is the only spring on the west side of the creek, there is no doubt of its identity. In 1804 this had a temperature of 132° . In 1859 its temperature was 133° , according to Owen, and to-day it is but 114.8° .

Amount of outflow.—The comparison of outflow is more difficult. According to Dunbar and Hunter the largest spring had an outflow of 11 quarts in 11 seconds in 1804, corresponding to 22,100 gallons per day, and the 4 largest springs had an outflow of 165 gallons per minute, or 237,600 gallons per day. Dr. Owen gives no measurements, but Glasgow gives the discharge of each spring—a total of 317 gallons per minute, or 450,480 gallons per day, as compared with 850,000 gallons per day at the present time. As the writer has shown elsewhere, the spring water is of meteoric origin, like most spring water, and probably varies somewhat from year to year, corresponding to variation in annual rainfall at some previous year, so that no definite comparison can be made with the early records, except to state that the volume of water discharged is very much greater. Supposing a practically constant amount of heat applied, this of itself would mean a slightly lowered temperature. In this connection attention should be called to the well put down by Maj. Torney, United States Army, in the Army and Navy Hospital, which is capable of yielding the amazing amount of 350,000 gallons per day without affecting but one very small spring (No. 40 of the list).

From a consideration of all these facts it is concluded that the springs are losing their heat so slowly that the loss is almost inappreciable.

Amount of mineral matter carried in solution by the waters.—No essential difference in the composition of the waters can be detected by a comparison of the analyses made for Owen or Larkin (1859) or for Dr. Branner, of the State geological survey, in 1889, with the elaborate and careful analyses made by the National Government. The waters are remarkable more for their purity than for their mineral contents. The material in solution consists mainly of silica, calcium, and bicarbonates. The total mineral matter discharged by all

the springs amounts to about 250 tons a year. The annual removal of this amount of material from the earth's interior to the surface must ultimately result in the formation of large cavities.

SOURCE OF HEAT.

While there have been many theories advanced to account for the source of the hot waters, the only hypothesis that stands the test of scientific inquiry is the one which ascribes the heat of the waters to still hot but concealed bodies of igneous rock. It seems scarcely necessary to call attention to the absurdity of the idea that either slaking lime in the depths of the earth or chemical reaction of the waters with the atmosphere could be the cause of the heat. That the waters come from a depth sufficient for their heating by the normal increment of earth heat (1° for every 50 feet) seems unreasonable, since it would necessitate a depth of nearly 5,000 feet to give the waters their present temperature, even assuming that they were not cooled in their course upward. The composition of the gases given off by the waters shows that they contain atmospheric air as well as carbon dioxide. That the heat of the waters is due to the heat developed by the folding of the rocks, which is the theory given to account for the heat at the Virginia Hot Springs, is not probable, for the folding at Hot Springs is not more intense than elsewhere in the mountain regions of Arkansas, and no evidence of hot spring action has been found at any other localities except where igneous rocks are present.

It is believed that the heat comes from a great body of still heated igneous rocks intruded in the earth's crust by volcanic agencies and underlying a large part of central Arkansas. The existence of such a mass is shown by the great bodies of granite seen at Potash Sulphur Springs and Magnet Cove, where the rocks have been exposed by the wearing down of the overlying sediments, though the igneous rocks seen were of course long since cooled. At Magnet Cove, moreover, there are tufa deposits which show the former occurrence of hot springs.

This hypothesis is strengthened by the occurrence of intrusive dikes at various localities about the springs, and their trend and occurrence indicate that the molten material which filled the fissures did not come from the bodies of rock now exposed at Potash Sulphur Springs or at Magnet Cove, but had some deep-seated source, whose location is indicated by the dikes as being approximately under the hot springs. Deep-seated waters converted into vapors by contact with this "batholith" of hot rock probably ascend through fissures toward the surface, where they probably meet cold spring waters which are heated by the vapors. As the igneous dikes near by are fissures reaching down to this great mass of igneous magma which have been filled by it to form dikes, it is not unreasonable to suppose that fissures extend down to the now solid but still hot igneous mass.

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